January, 1998
NSRP 0490

SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
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WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Industry Standards for Hull Structural Penetration Design Criteria and Details

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Newport News Shipbuilding

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **JAN 1998**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **The National Shipbuilding Research Program, Industry Standards for Hull Structural Penetration Design Criteria and Details**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230-Design Integration Tower Bldg 192, Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**70**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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NSRP 0490

* * *

INDUSTRY STANDARDS FOR HULL STRUCTURAL PENETRATION DESIGN CRITERIA AND DETAILS

* * *

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For

PANEL SP-6
MARINE INDUSTRY STANDARDS

Under the

NATIONAL SHIPBUILDING RESEARCH PROGRAM

* * *

FEBRUARY 1997

INDUSTRY STANDARDS FOR HULL STRUCTURAL PENETRATION DESIGN CRITERIA AND DETAILS

Contents :

Executive Summary iii

Acknowledgment...iv

1.0 Introduction... 1-1

2.0 Approach 2-1

3.0 Penetration Standard Guidelines – Notes.. 3-1

4.0 Penetration Standard Guidelines -- Criteria & Details Graphics 4-1

5.0 Penetration Standard Guidelines -- Design Criteria Tables......................... 5-1

6.0 Conclusions & Recommendations 6-1

Appendix

A. Technical Report.. A-1

EXECUTIVE SUMMARY

"Industry Standards For Hull Structural Penetration – Design Criteria And Details" employs state-of-the-art engineering concepts, guidance and standards and provides shipyard designers an improved, consolidated and easy to use design handbook for penetrations in secondary ship structure and small discretionary openings in primary ship structure. Penetrations designed using this handbook will significantly reduce the design cycle time, will be optimized and simplified for labor and cost reduction, and will subsequently reduce overall ship construction time and cost. The handbook should be used as a tool to streamline engineering, design and construction practices to improve production throughput in a shipyard and make the ship production process more competitive.

Each shipyard and regulatory agency has its own standards and guidelines for the methods to be employed when distributive systems penetrate hull structure. While these guidelines and practices have been used for decades, no industry-wide standards for penetrations in secondary ship structure exist. In designing penetrations designers and engineers must either follow past practice, perpetuating designs that might be inefficient or difficult to produce, or must undertake expensive analyses to ensure the strength and reliability of the design, resulting in delays and high costs. Implementing a variety of designs or not having any penetration standards increases the engineering costs and decreases the benefits which can be achieved from commonality in design and production.

To reduce the time and expense of penetration design and manufacture, this handbook establishes guidelines for achieving penetrations with satisfactory performance in a faster time frame and with a high level of commonality. By doing so it attempts to:

- Lessen or eliminate varying designs.
- Simplify the penetration design process, reducing unnecessary analysis.
- Eliminate needless rules, permitting designers of distributive systems more flexibility in their arrangements.

These areas offer a high potential for reduction in time and cost associated with the design and systems installation processes.

The Standard Penetration Handbook will enhance the design development process and help to establish common and standardized designs, leading to faster cycle time and thereby achieving time and cost reduction. This document will also provide a basis to further extend the standard penetration design guidelines to special and high-strength steel, and to special purpose ship structures.

ACKNOWLEDGMENT

This project was funded by the National Shipbuilding Research Program, Marine Industry Standards Panel (SP-6), chaired by Steve Laskey of Bath Iron Works Co. Program management for the project was provided by Newport News Shipbuilding. The SP-6 Panel is one of the Ship Production Committee Panels of the Society of Naval Architects and Marine Engineers, which were established with the purpose of improving U.S. shipbuilding performance.

An extensive survey was conducted on the guidelines, rules and practices of ship structural penetration design and production with several shipyards and regulatory bodies, and their feedback and recommendations are included in this standard. The authors acknowledge and appreciate the interest and participation of the following shipyards and regulatory bodies : Alabama Shipyard Inc.; Avondale Shipyards; Bath Iron Works; Ingalls Shipbuilding; National Steel & Shipbuilding Company; Newport News Shipbuilding; ABS Americas and United States Coast Guard.

The success of this project was accomplished through the efforts of many VIBTECH personnel. The authors would like to extend special thanks to Geoffery Rivinius for his valuable contribution.

INDUSTRY STANDARDS FOR HULL STRUCTURAL PENETRATION DESIGN CRITERIA AND DETAILS

1.0 Introduction

This NSRP project is to develop a handbook of standards and design guidelines for structural penetrations in secondary ship structure. This handbook is developed for the entire shipbuilding community as an industry standard to be used for years to come, and to provide base-line ground work for penetration standards for special cases. The handbook contains design criteria and details for use by designers and drafters to expedite ship construction drawing development. These design criteria and details provide guidance that will enable designers and drafters to design penetrations without resorting to time consuming engineering review of each penetration.

2.0 Approach

Standard penetration design criteria and details are developed through parametric evaluation of ship structural openings and structural configurations, using first principle engineering and detail finite element analyses. The technical approach taken to accomplish this project and develop the handbook can be broadly categorized in five successive tasks, i.e., Information Search; Collation of Information; Design Guidelines Development; CAD Drawings and Database Development; & Standard Hull Structural Penetration Handbook Development. These tasks are described and discussed in detail in the Appendix A -- Technical Report.

3.0 Penetration Standard Guidelines -- Notes

1. GENERAL NOTES

1.A Use penetrations only when absolutely necessary.

1.B Penetrations of structural members carrying extreme and concentrated loads should be referred to engineering.

1.C On all guidelines S represents the span between supports (bulkhead to bulkhead, stanchion to bulkhead, stanchion to stanchion, or from a support point to the side shell).

1.D Types of penetrations which are highly recommended are unreinforced circles and flat ovals. Where possible, rectangular openings should be replaced with flat ovals or have ample radius in the corners.

1.E Necessary penetrations should be positioned in the structure in such a way to minimize the need for any compensation.

1.F Locations where penetrations are discouraged, but are permitted with necessary compensations **only** after validating with engineering include:

- i) Sheer Strakes, Bilge Strake and Strength Deck Stringer Plates within the midship 3/5 length.
- ii) Shell Plating 1/4 length fore and aft of amidships, where shear stresses are high.
- iii) Pillars, Stanchions or Girder Webs directly above or below a Pillar, Stanchion or a Structural Bulkhead directly above or below a Pillar or Stanchion.
- iv) Brackets and Flanges of Beams, Girders, Webs or Stiffeners.

1.G Locations where penetrations are permitted based on these design guidelines include:

- i) Secondary Structures, which are not a part of primary hull structure.
- ii) Transverse Deck Girders and Side-shell Frames.
- iii) Double Bottom Floors.
- iv) Non-structural Bulkheads and Decks.
- v) Superstructures and Deckhouses.

1.H Locations where penetrations are permitted based on these design guidelines, **only** after validating with engineering include:

- i) Strength Decks
- ii) Structural Bulkheads
- iii) Longitudinal Girders
- iv) Side Shell Plating

1.I Any questions regarding the definition or extent of any of the above terms should be directed to engineering.

1.J To keep penetrations to a minimum it is essential to have good communication between systems design groups, penetration control, production engineering and planning.

1.K It is important to maintain a standard for the cutting of the holes, i.e., the opening edges should at least have the same level of finish as that of automatic flame-cut edges (use existing shipyard standards or consult classification societies).

1.L It is important to maintain a standard for welding on compensations of holes (use existing approved shipyard standards or consult classification societies).

2. Penetration Location

2.A Where it is necessary to have openings sited near one another in the deck plating, they should be arranged in the same fore and aft line, then advantage can be made of the mutual stress-relieving characteristics.

2.B Penetrations in decks should be located between the fore and aft parallel lines covering the central 2/3 width, to take advantage of the shear-lag phenomenon (the diffusion of direct stresses from deck centerline to deck edge).

2.C Openings in Watertight Transverse Subdivision Bulkheads should be restricted to watertight doors and holes for piping & cables. The latter should be grouped together to be used with transits.

2.D Openings in Bulkheads above arches and doors should be avoided, except as shown in Figure 14.

2.E Compensation is not normally required for openings cut in non-watertight Bulkheads as long as local strength requirements are satisfied.

2.F When an opening cuts across a number of longitudinals, the longitudinal shall be cranked (knuckled) outboard to provide structural continuity, thereby minimizing stress concentration at the opening edges. The knuckle in the longitudinal should be made in close proximity to the Transverse, i.e., within 1 inch, ensuring allowance for clearance between adjacent welds. Where cranking of longitudinal members is either excessive or not practical, it is recommended to terminate the longitudinal member (s) at a frame and transfer longitudinal loads outboard by inserting transverse members. See Figure 18.

2.G In strength decks, secondary holes adjacent to major openings shall be restricted in accordance with Figure 12.

2.H Openings in Beams, Girders, Webs and stiffeners should be located in the web near the neutral axis of the member. The term Bay used in figures is defined as the length of the penetrated member between adjacent stiffeners running in the orthogonal direction. See Figure 20.

2.I In Beams, Webs and Girders uncompensated openings are not allowed in the 33% of web depth towards the flange, and compensated openings are not allowed in the 25% of web depth towards flange. See Figure 1 and 2.

2.J A single row of round holes in the web of beams and stiffeners, to accommodate cabling is usually acceptable anywhere in the beam without compensations, provided it meets the criteria described in Figure 7.

2.K Separation between adjacent openings should not be less than one-half the sum of the adjacent openings. When that is not possible, the penetrations should be combined to form a single opening, and adequately reinforced.

2.L Openings which penetrate plating within a distance of the web frames equal to half the effective breadth of plating should be avoided. Where unavoidable, such penetrations should be reinforced to maintain the strength of the web frame. See Figure 13.

2.M The edge of the penetrations should be at least 3 inches away from a weld seam in the main structure (i.e. strength decks, shell plating, longitudinal strength and main transverse bulkheads, erection butts at assembly breaks, and other high stress areas). Penetrations at other seam welds should either be centered on the seam or at least 2 inches to the edge of the hole away from the seam.

3. Penetration Size

3.A Uncompensated openings should not be deeper than 33% of the web depth of the structural member. See Figure 1.

3.B Compensated openings should not be deeper than 50% of the web depth of the structural member. See Figure 2. Where an excessive hole dimension is required, the web depth should be increased, or heavier reinforcing should be installed as determined by specific engineering analysis.

3.C Non-circular openings in a beam should have an aspect ratio of 2 or less with the maximum dimension in the governing stress direction not greater than 80% of the depth of the beam. See Figure 1 and 3.

3.D Rectangular openings shall have radius corners of preferably 1/4 and not less than 1/5 of the penetration dimension perpendicular to the direction of governing stresses. See Figure 3.

4. Penetration Shape and Orientation

4.A Openings whose greatest dimension is less than ten times the thickness of the plating should be circular. Otherwise openings may be either rectangular or flat oval.

4.B Rectangular and elliptical openings should be replaced with flat oval, if possible, with the larger dimension parallel to the direction of governing stresses.

4.C For small openings the corner should be radiused, whereas for large openings such as exhaust uptakes and removal routes, streamlined corner profiles are preferred. See Figure 19.

4.D Flatoval and elliptical openings should be aligned with the major axis parallel to the direction of governing stress.

4.E Rectangular openings / Square openings should be aligned with the longest side / any side, parallel to the direction of governing stress.

5. Penetration Reinforcements

5.A When design criteria limits stated in earlier sections and shown in Figures 1, 3 and 5 are exceeded, then strength compensation in the form of reinforcement is necessary.

5.B Compensation for openings are achieved by:

(i) Using a formed flat bar, also called face bar.
(ii) Using a section of standard pipe or spool.
(iii) Installing a coaming.
(iv) Installing doublers or insert plates.

5.C Adequate compensation may be inherent to the penetrating system. Penetrations of this type are:

(i) Electrical stuffing tubes.
(ii) Electrical or piping transit frame.
(iii) Pipes welded to the structure penetrated.
(iv) Ventilation or A/C spools whose thickness is not less than the structure penetrated.

5.D In general use doublers or inserts when existing penetrations violate width (height) requirements, and use face bars when existing penetrations violate length requirements.

5.E Compensation sizing criteria for various compensation types are described as follows:

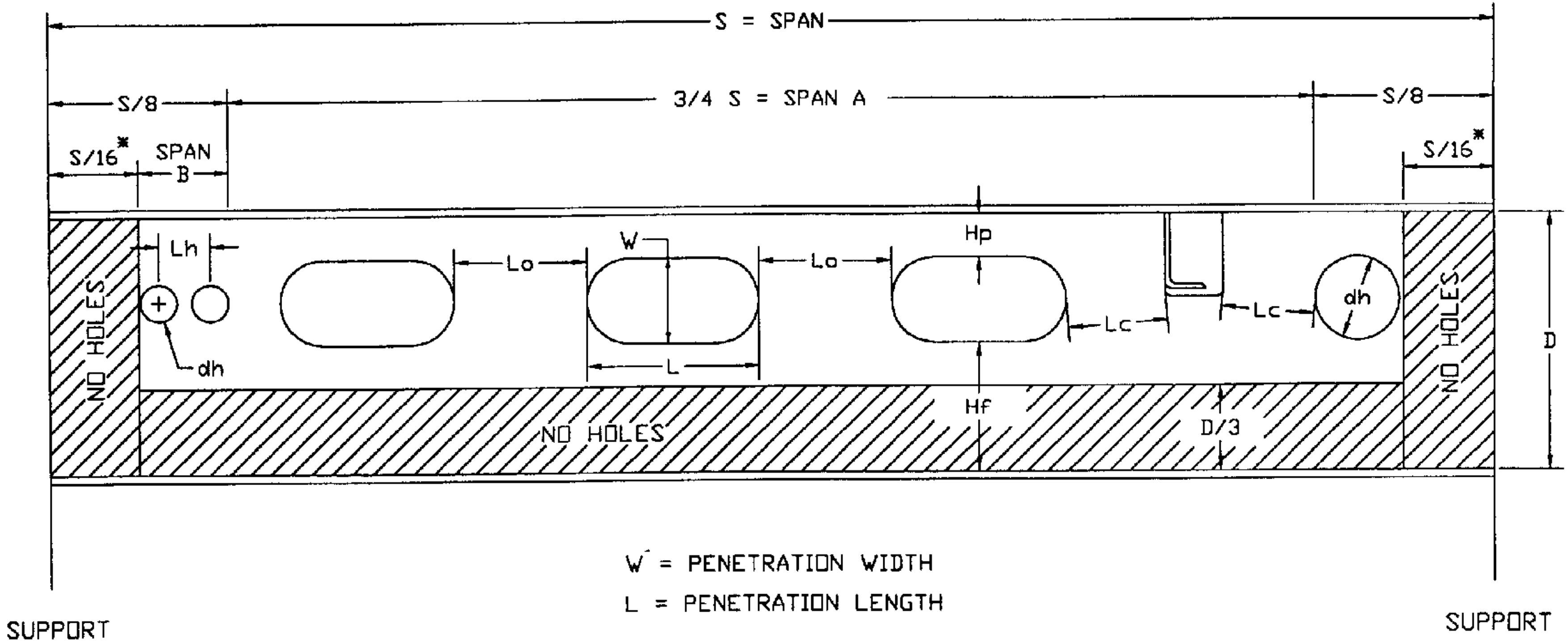
(i) Doublers -- See Figure 9
(ii) Face Bar -- See Figure 10
(iii) Insert Plate -- See Figure 11

5.F Standard pipe sizes should be used for Face bar compensations in case of circular openings, wherever possible.

5.G Standard compensation tables provided with the design guidelines can also be used to readily obtain compensation sizing.

4.0 Penetration Standard Guidelines -- Criteria & Details Graphics

UNCOMPENSATED FLATOVAL PENETRATIONS



W = PENETRATION WIDTH

L = PENETRATION LENGTH

SIZING CRITERIA

MIDDLE 3/4 = SPAN A	END S/8 = SPAN B	
L ≦ 0.66D	SINGLE HOLE :	dh ≦ 0.33D
W ≦ 0.33D		
Lo ≧ L		
Lc ≧ 8"	MULTIPLE HOLES :	dh ≦ 0.2D
Hf ≧ 0.33D		Lh ≧ 2dh
Hp ≧ 3"		

*NOTE : USE S/16 BUT NOT TO BE LESS THAN ONE BAY

CHECK WITH ENGINEERING ON ALL PENETRATIONS IN END S/8

NSRP SP-6-95-3

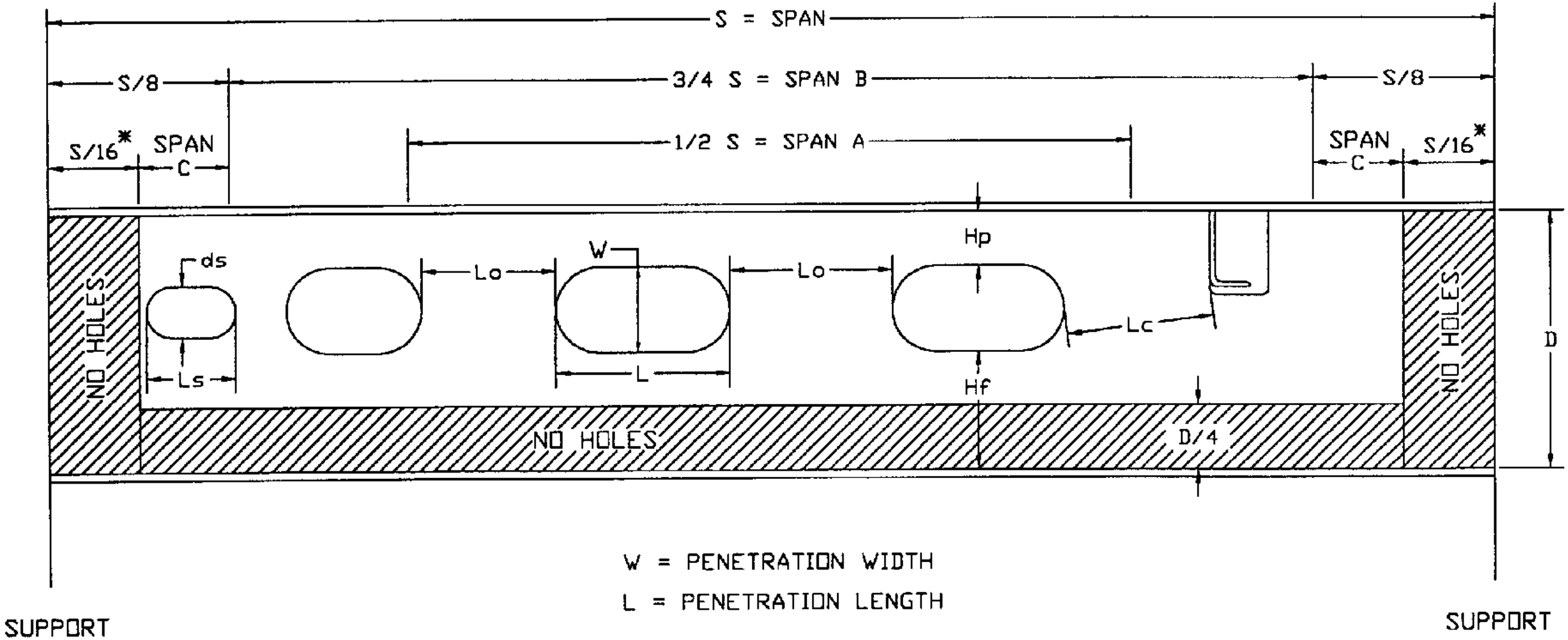
PENETRATIONS IN HULL STRUCTURE

VIBTECH, INC.

NONE

FIG. 1

COMPENSATED FLATOVAL PENETRATIONS



W = PENETRATION WIDTH

L = PENETRATION LENGTH

SIZING CRITERIA USING DOUBLER, FLATBAR, OR INSERT PLATE

MIDDLE 1/2 = SPAN A	MIDDLE 3/4 = SPAN B	END S/8 = SPAN C
L ≦ 1.5D	L ≦ 1.0D	Ls ≦ 0.5D
W ≦ 0.5D	W ≦ 0.5D	ds ≦ 0.33D
Lo ≧ D/3	Lo ≧ D/3	
Lc ≧ 3"	Lc ≧ 3"	
Hf ≧ D/4	Hf ≧ D/4	
Hp ≧ 1"	Hp ≧ 1"	

*NOTE : USE S/16 BUT NOT TO BE LESS THAN ONE BAY
CHECK WITH ENGINEERING ON ALL PENETRATIONS IN END S/8

NSRP SP-6-95-3

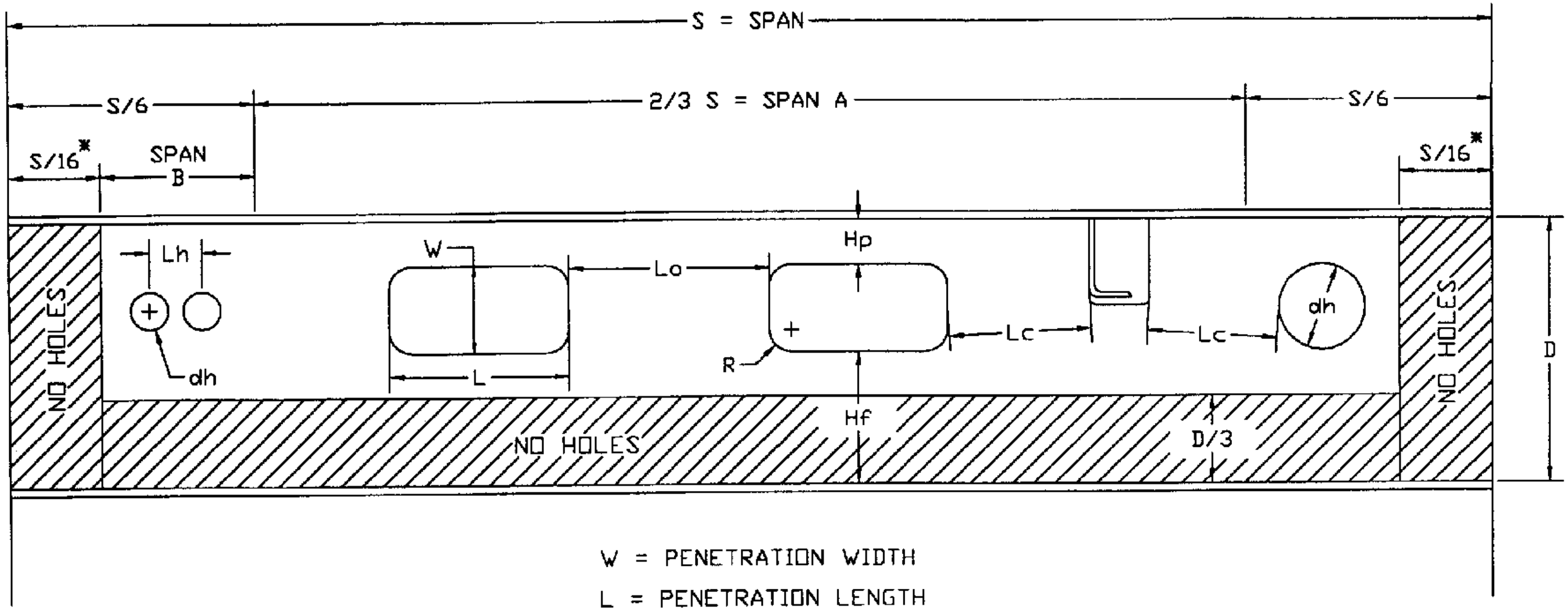
PENETRATIONS IN HULL STRUCTURE

VIBTECH, INC.

NONE

FIG. 2

UNCOMPENSATED RECTANGULAR PENETRATIONS



W = PENETRATION WIDTH

L = PENETRATION LENGTH

SUPPORT

SUPPORT

SIZING CRITERIA

MIDDLE 2/3 = SPAN A	END S/6 = SPAN B
L ≦ 0.66D	SINGLE HOLE : dh ≦ 0.33D
W ≦ 0.33D	
R ≧ 0.25W	
R ≧ 1.5"	MULTIPLE HOLES : dh ≦ 0.2D
Lo ≧ L	Lh ≧ 2dh
Lc ≧ 8"	
Hf ≧ 0.33D	
Hp ≧ 3"	

*NOTE : USE S/16 BUT NOT TO BE LESS THAN ONE BAY

CHECK WITH ENGINEERING ON ALL PENETRATIONS IN END S/8

NSRP SP-6-95-3

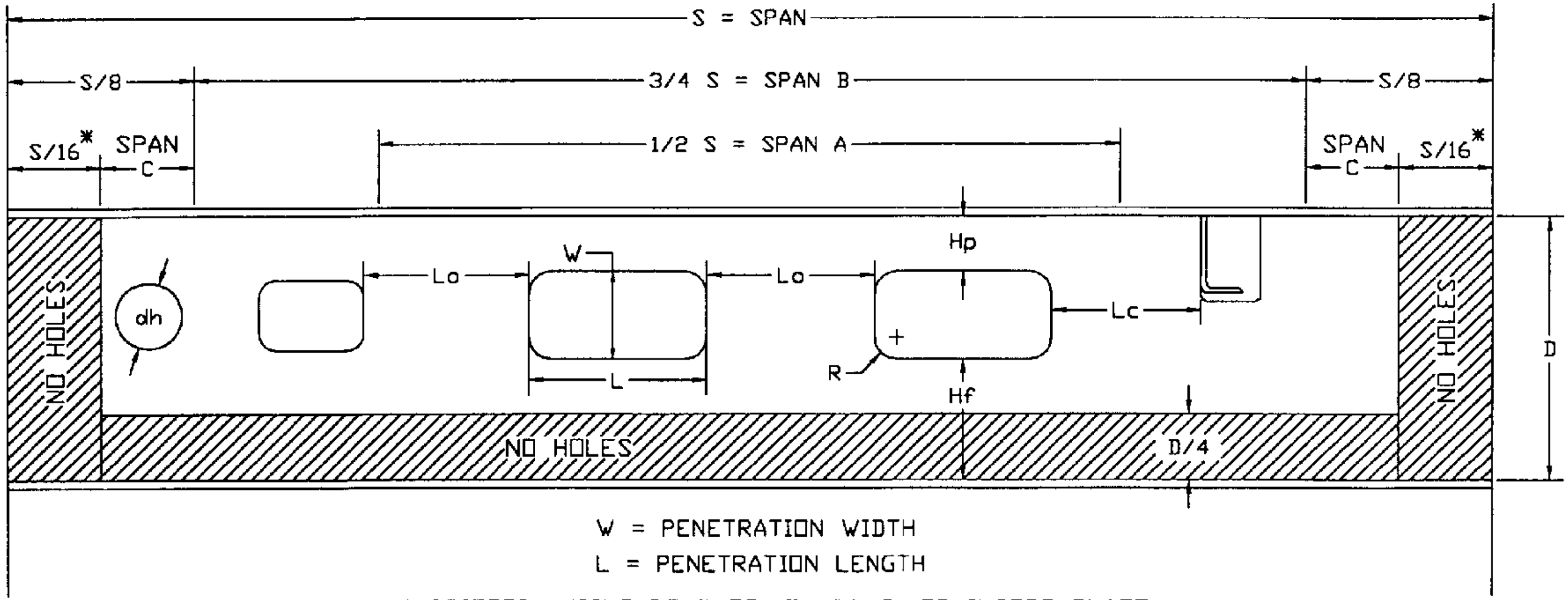
PENETRATIONS IN HULL STRUCTURE

VIBTECH, INC.

NONE

FIG. 3

COMPENSATED RECTANGULAR PENETRATIONS



SUPPORT

SUPPORT

W = PENETRATION WIDTH

L = PENETRATION LENGTH

SIZING CRITERIA USING DOUBLER, FLATBAR, OR INSERT PLATE

MIDDLE 1/2 = SPAN A	MIDDLE 3/4 = SPAN B	END S/8 = SPAN C
$L \leq 1.2D$	$L \leq 0.66D$	$dh \leq 0.4D$
$W \leq 0.5D$	$W \leq 0.4D$	
$R \geq 0.25W$	$R \geq 0.25W$	
$R \geq 1.5''$	$R \geq 1.5''$	
$Lo \geq D/2$	$Lo \geq D/2$	
$Lc \geq 4''$ †	$Lc \geq 4''$ †	
$Hf \geq D/4$	$Hf \geq D/4$	
$Hp \geq 1''$	$Hp \geq 1''$	

† FOR Lc < 6" USE DOUBLERS OR INSERT PLATE COMPENSATION

* NOTE : USE S/16 BUT NOT TO BE LESS THAN ONE BAY

CHECK WITH ENGINEERING ON ALL PENETRATIONS IN END S/8

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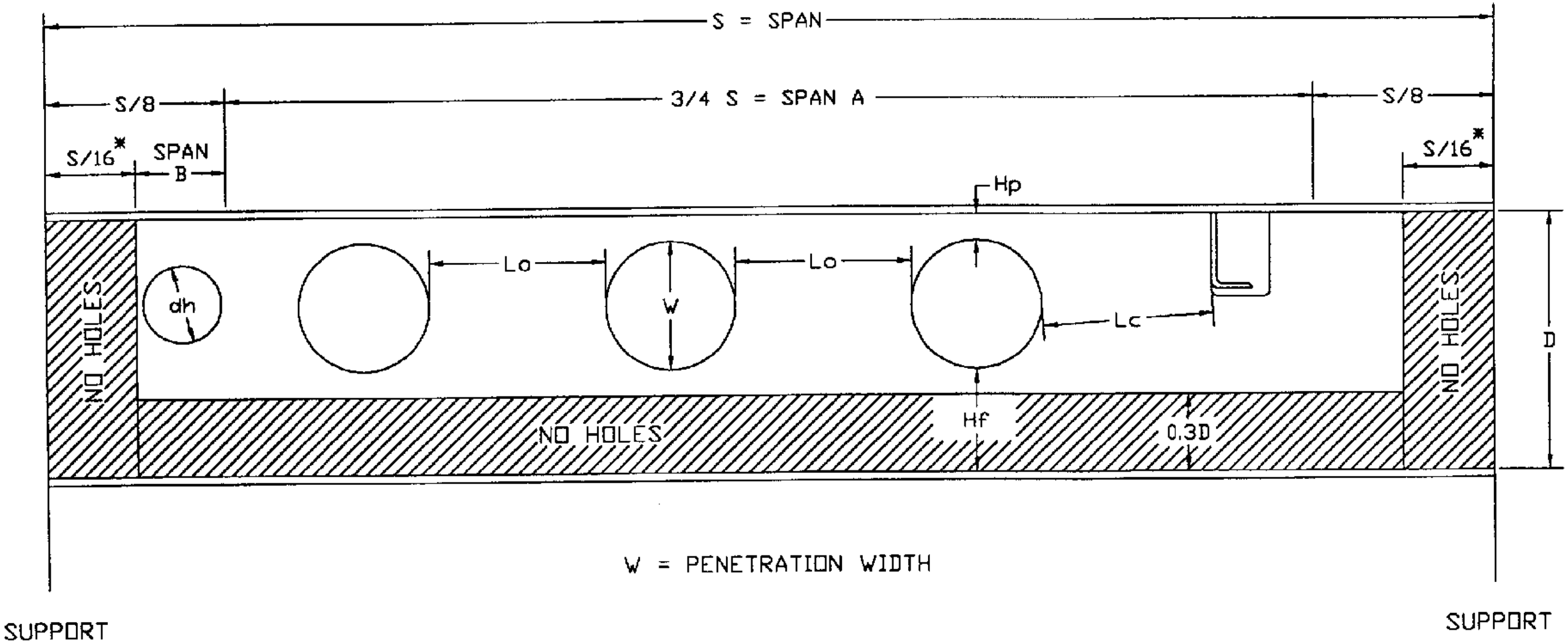
PENETRATIONS IN HULL STRUCTURE

VIRTECH, INC.

NONE

FIG. 4

UNCOMPENSATED CIRCULAR PENETRATIONS



SIZING CRITERIA

MIDDLE 3/4 = SPAN A	END S/8 = SPAN B
W ≦ 0.5D	dh ≦ 0.33D
Lo ≧ W	
Lc ≧ 8"	
Hf ≧ 0.3D	
Hp ≧ 3"	

*NOTE : USE S/16 BUT NOT TO BE LESS THAN ONE BAY

CHECK WITH ENGINEERING ON ALL PENETRATIONS IN END S/8

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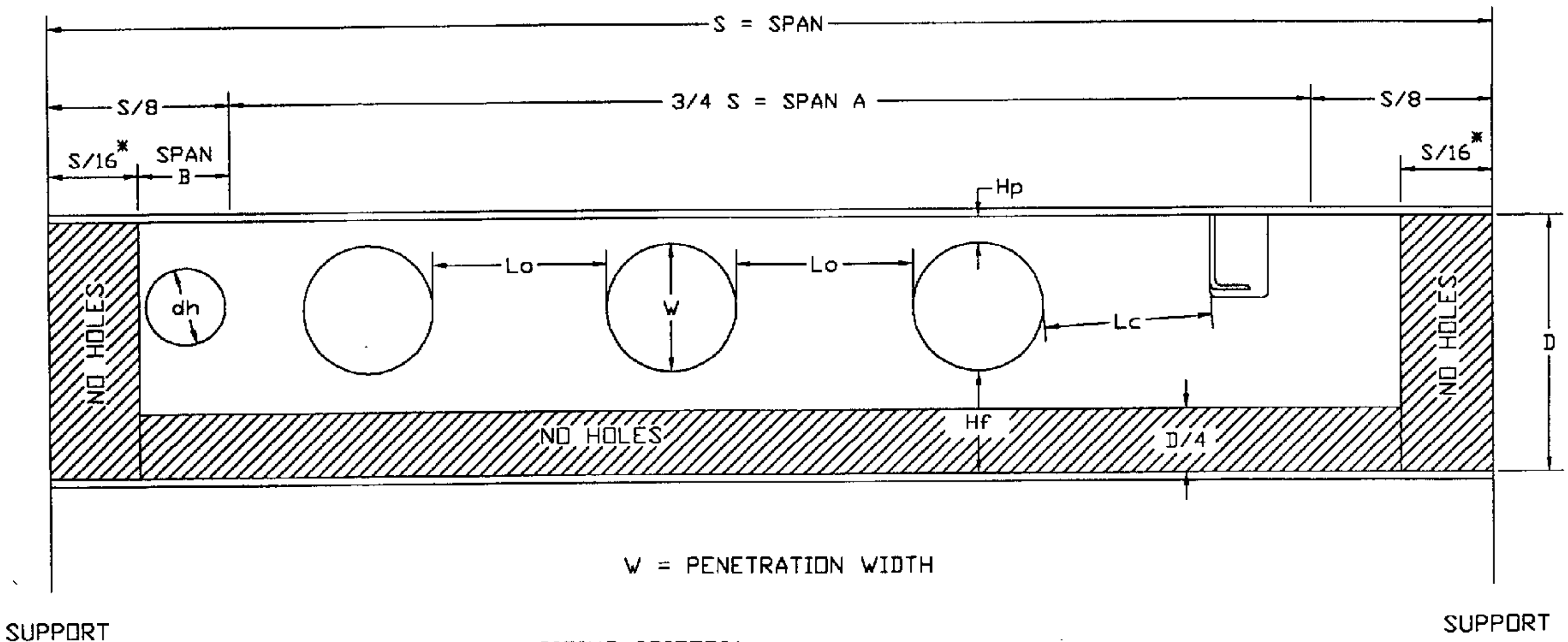
PENETRATIONS IN HULL STRUCTURE

VIBTECH, INC.

NONE

FIG. 5

COMPENSATED CIRCULAR PENETRATIONS



SIZING CRITERIA

MIDDLE 3/4 = SPAN A	END S/8 = SPAN B
$W \leq 0.66D$	$dh \leq 0.4D$
$Lo \geq D/3$	
$Lc \geq 3'$ †	
$Hf \geq D/4$	
$Hp \geq 1'$	

† FOR Lc < 6' USE DOUBLERS OR INSERT PLATES COMPENSATION

*NOTE : USE S/16 BUT NOT TO BE LESS THAN ONE BAY

CHECK WITH ENGINEERING ON ALL PENETRATIONS IN END S/8

NSRP SP-6-95-3

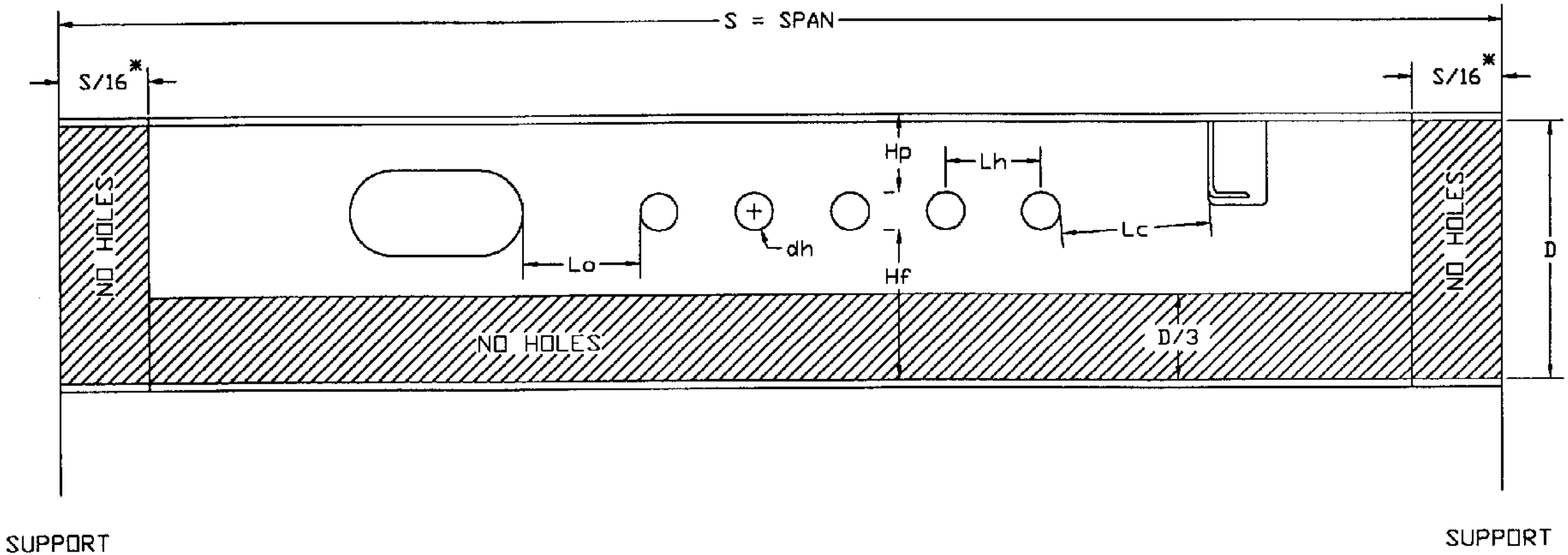
PENETRATIONS IN HULL STRUCTURE

VISTECH, INC.

NONE

FIG. 6

SERIES OF SMALL HOLES



SIZING CRITERIA: WITHOUT COMPENSATION

$dh \leq 0.2D$
$Lh \geq 2dh$
$Lc \geq 2dh$
$Lo \geq 2dh$
$Hf \geq 0.33D$
$Hp \geq 3''$
$Hp \geq 1''$ (WITH COMPENSATION)

* NOTE : USE S/16 BUT NOT TO BE LESS THAN ONE BAY
CHECK WITH ENGINEERING ON ALL PENETRATIONS IN END S/8

NSRP SP-6-95-3

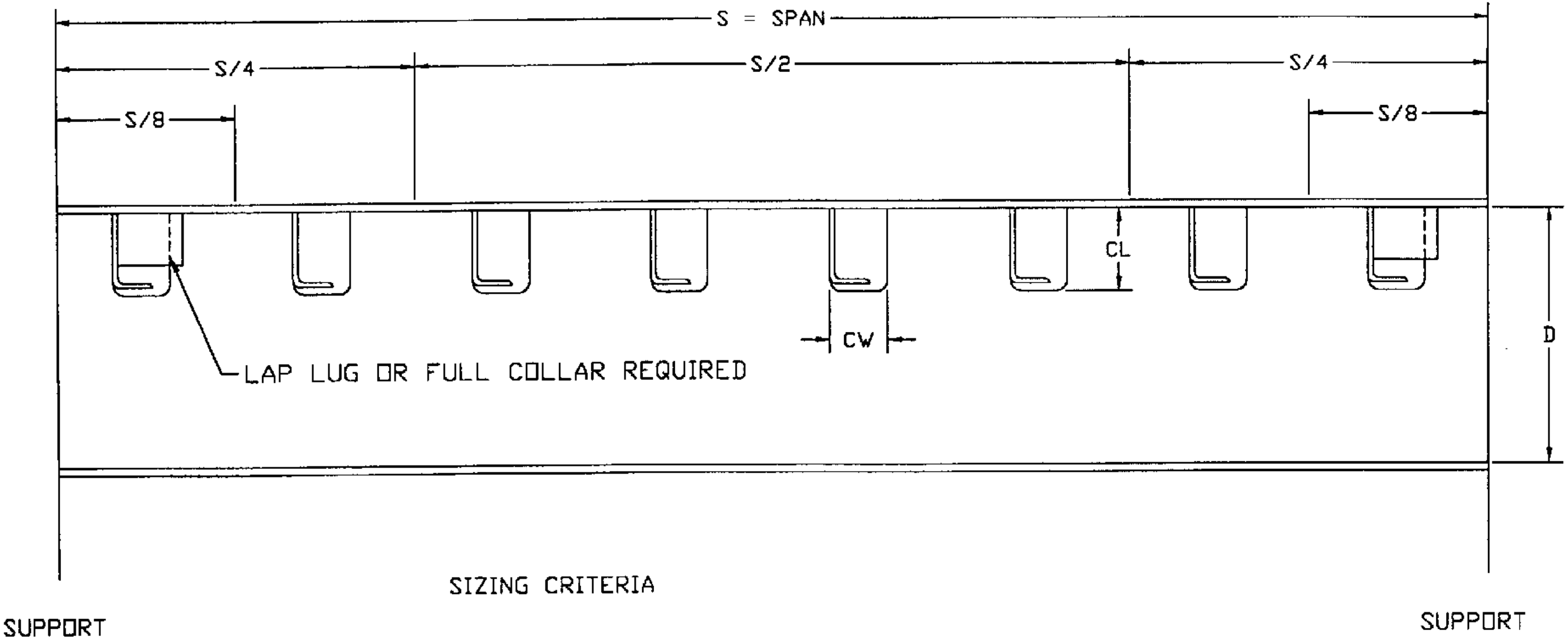
SERIES OF SMALL HOLES

VIRTECH, INC.

NONE

FIG. 7

CUT-OUT CONFIGURATIONS



SIZING CRITERIA

CUTOUT CL ≦ .33D

MIDDLE 3/4 S : NO COMPENSATION REQUIRED

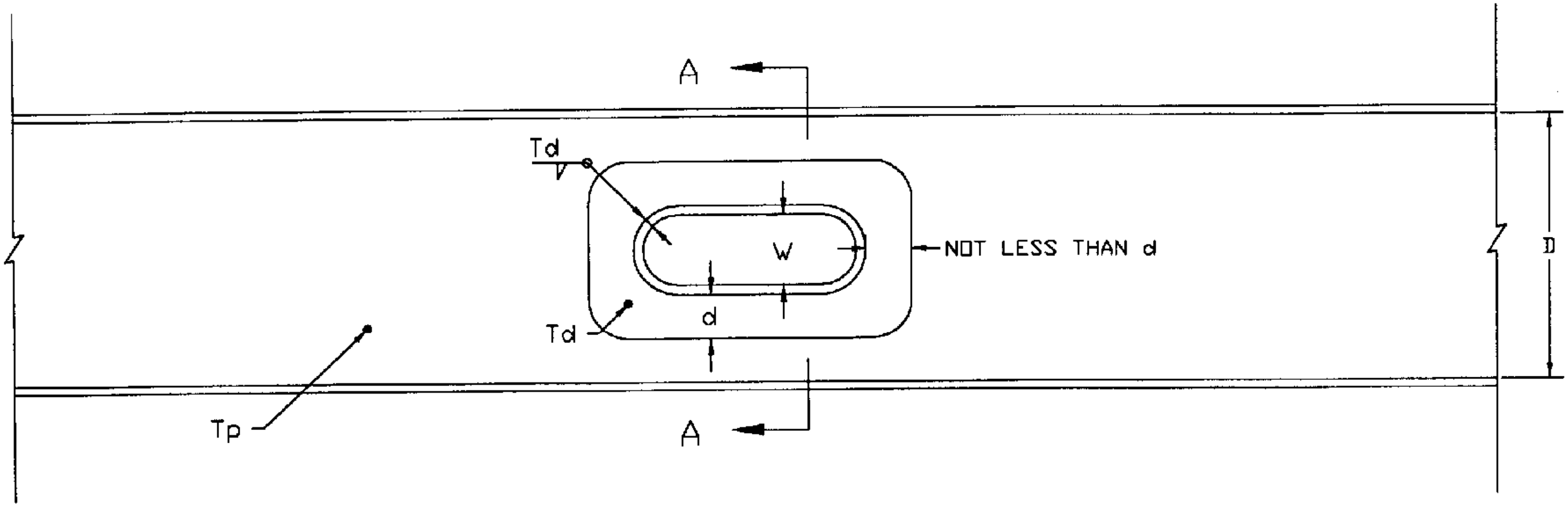
END S/8 : COMPENSATION REQUIRED (LAP LUG OR COLLAR)

CUTOUT .33D ≦ CL ≦ .5D

MIDDLE 1/2 S : NO COMPENSATION REQUIRED

END S/4 : COMPENSATION REQUIRED (LAP LUG OR COLLAR)

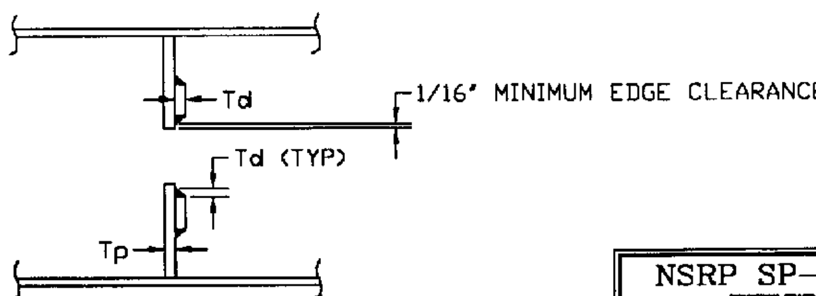
NSRP SP-6-95-3	
CUTOUTS IN HULL STRUCTURE	
VISTECH, INC.	
NONE	FIG. 8



SIZING CRITERIA

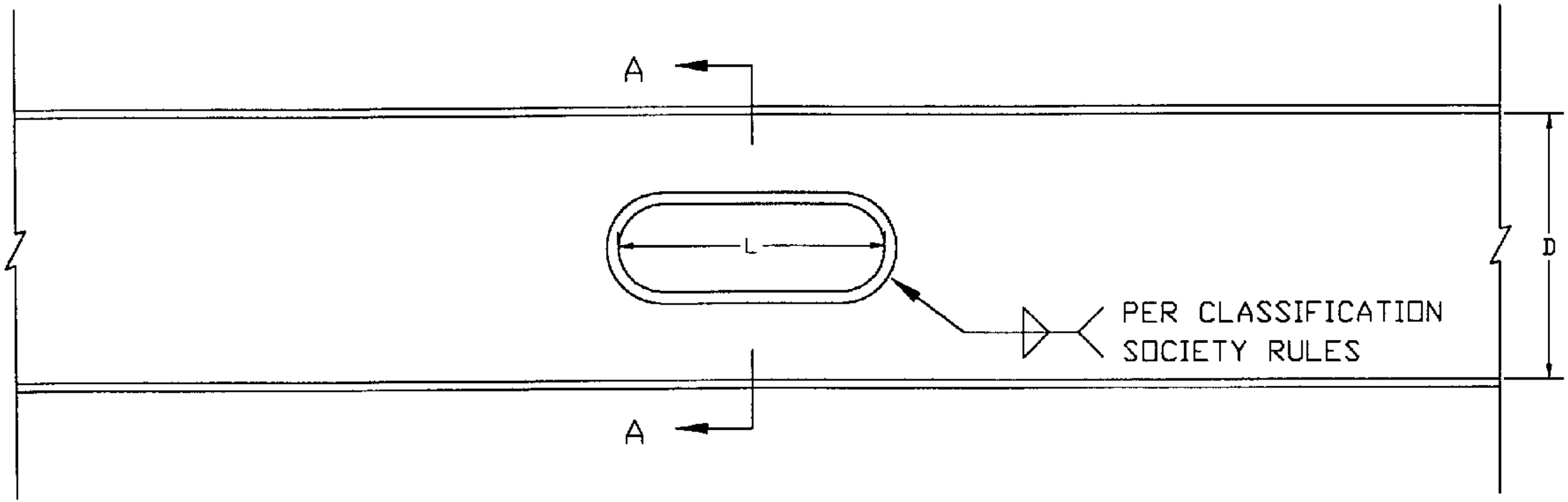
$$2 \times d \times Td = W \times Tp$$

$$1/4'' \leq Td \leq (Tp + 1/16'')$$



SECTION A-A

NSRP SP-6-95-3	
DOUBLER COMPENSATIONS	
VERTECH, INC.	
NONE	FIG. 9



SIZING CRITERIA

$.4 \times L \times Tp = 2 \times b \times Tc$

OR

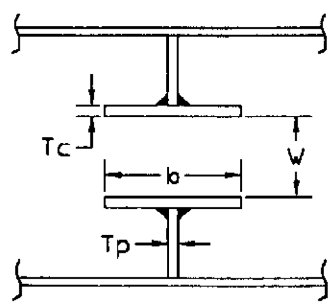
SEE TABLE

WITH

$(Tp - 1/8") \leq Tc \leq 2Tp$

$Tc \geq 1/4"$

$b \leq 16Tp$



SECTION A-A

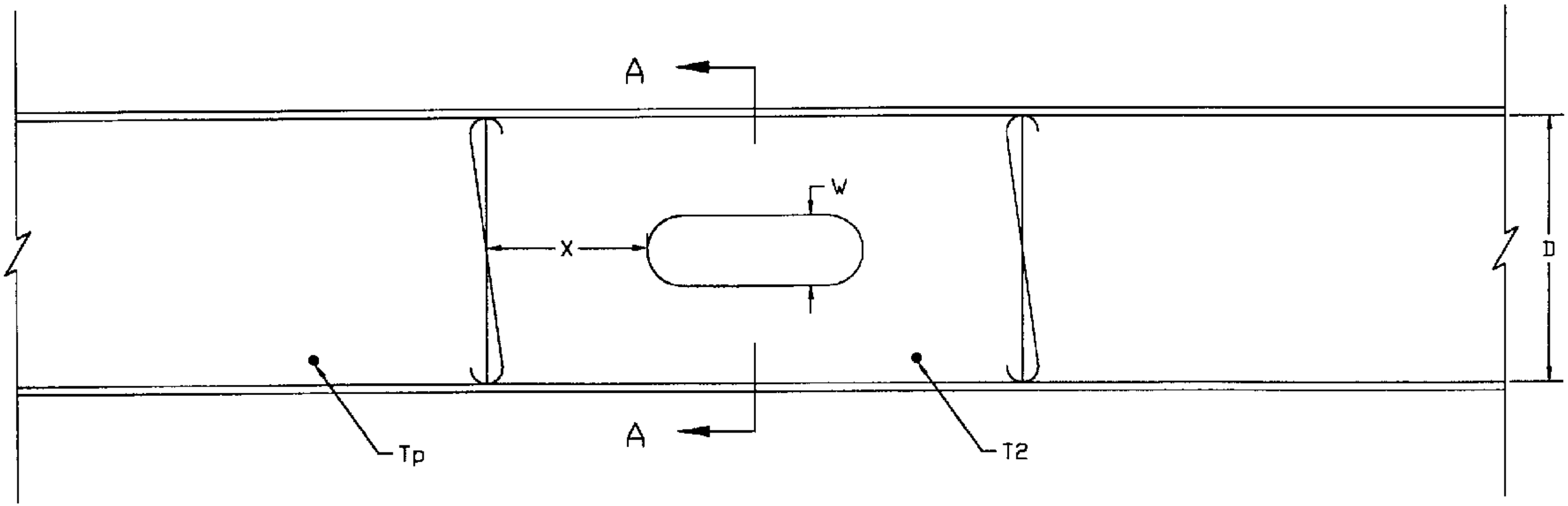
NSRP SP-6-95-3

FACE BAR
COMPENSATIONS

VIRTECH, INC.

NONE

FIG. 10



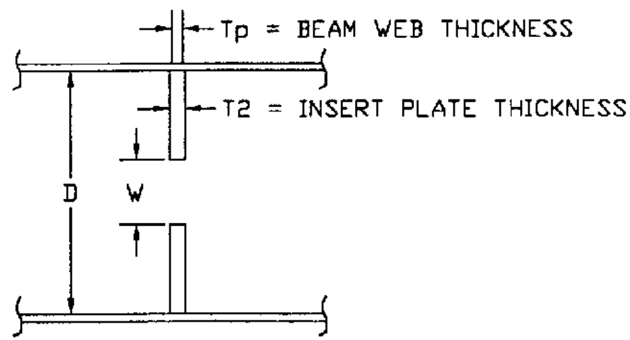
SIZING CRITERIA

$$(T_p \times D) = [T2 \times (D - W)]$$

$$X \geqq 3'$$

AND

$$X \geqq 0.75\ W$$



SECTION A-A

NSRP SP-6-95-3

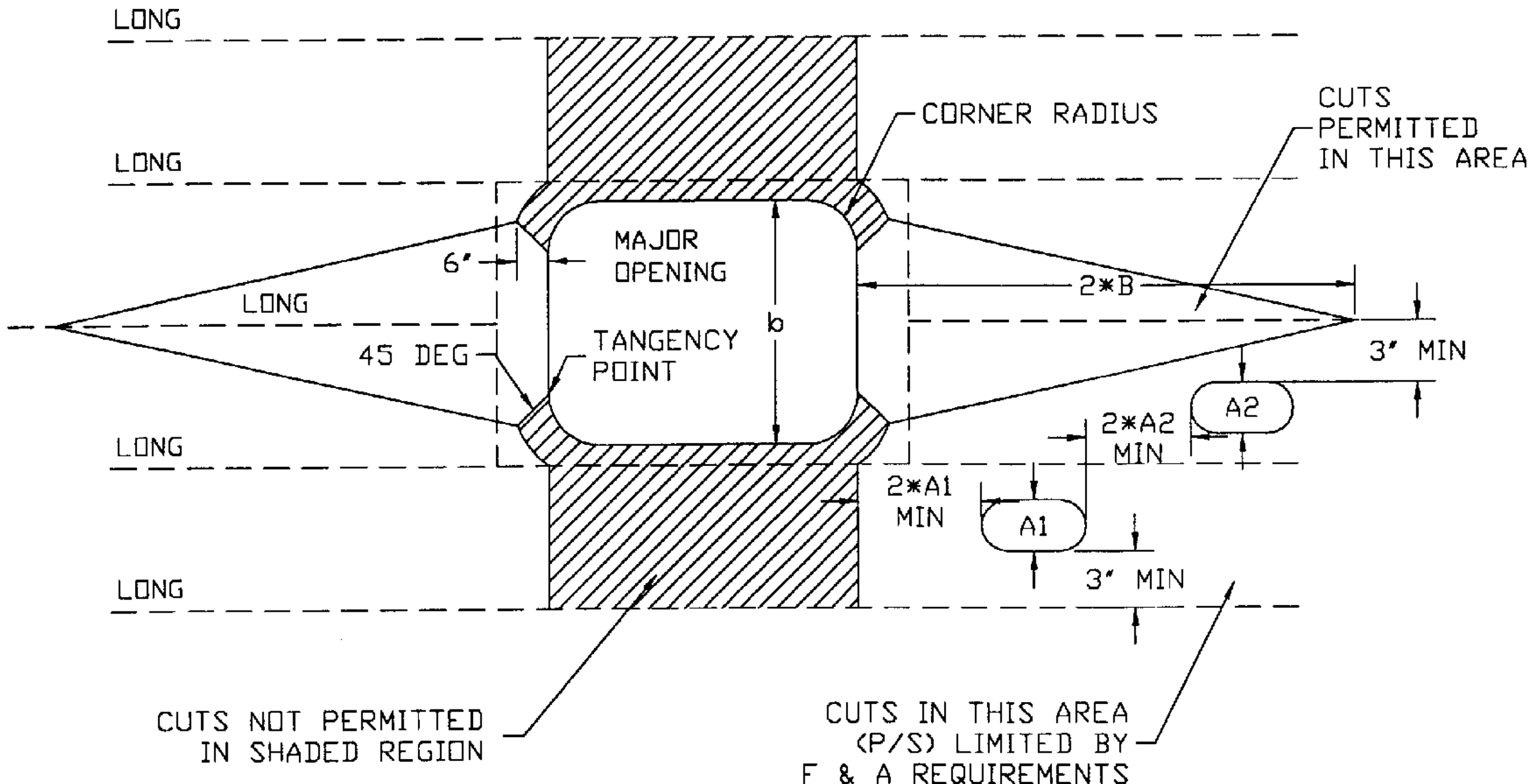
INSERT COMPENSATIONS

VIRTECH, INC.

NONE

FIG. 11

RESTRICTED AREAS FOR HOLES NEAR MAJOR OPENINGS IN DECKS



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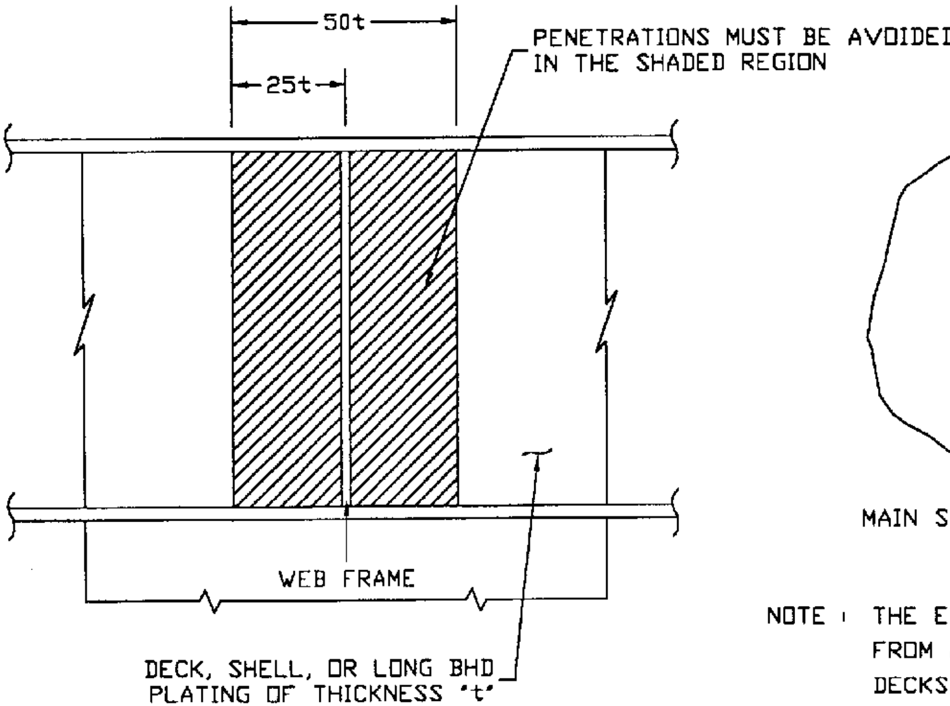
SECONDARY HOLES NEAR MAJOR OPENINGS IN DECKS

VEITCH, INC.

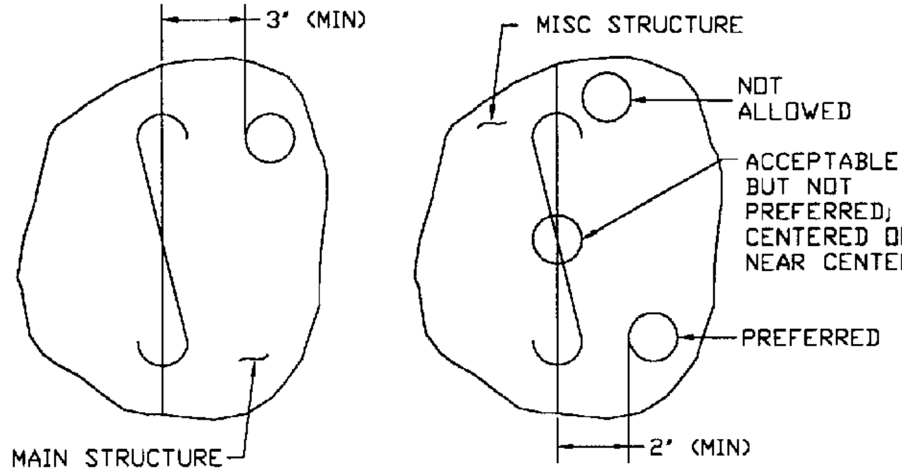
NONE

FIG. 12

MISCELLANEOUS AREAS



NOTE : OPENINGS WHICH PENETRATE PLATING WITHIN THE EFFECTIVE BREADTH OF PLATING FROM THE WEB SHALL BE AVOIDED. WHERE UNAVOIDABLE, SUCH OPENINGS SHALL BE REINFORCED SO THAT THE STRENGTH OF THE WEB FRAME IS NOT IMPAIRED.



NOTE : THE EDGE OF PENETRATIONS SHOULD BE AT LEAST 3" AWAY FROM A WELD SEAM IN THE MAIN STRUCTURE (I.E. STRENGTH DECKS, SHELL PLATING, LONGITUDINAL STRENGTH AND MAIN TRANSVERSE BULKHEADS, ERECTION BUTTS AT ASSEMBLY BREAKS, AND OTHER HIGH STRESS AREAS). PENETRATION AT OTHER SEAM WELDS SHOULD EITHER BE CENTERED ON THE SEAM OR AT LEAST 2" TO THE EDGE OF THE HOLE AWAY FROM THE SEAM.

NSRP SP-6-95-3

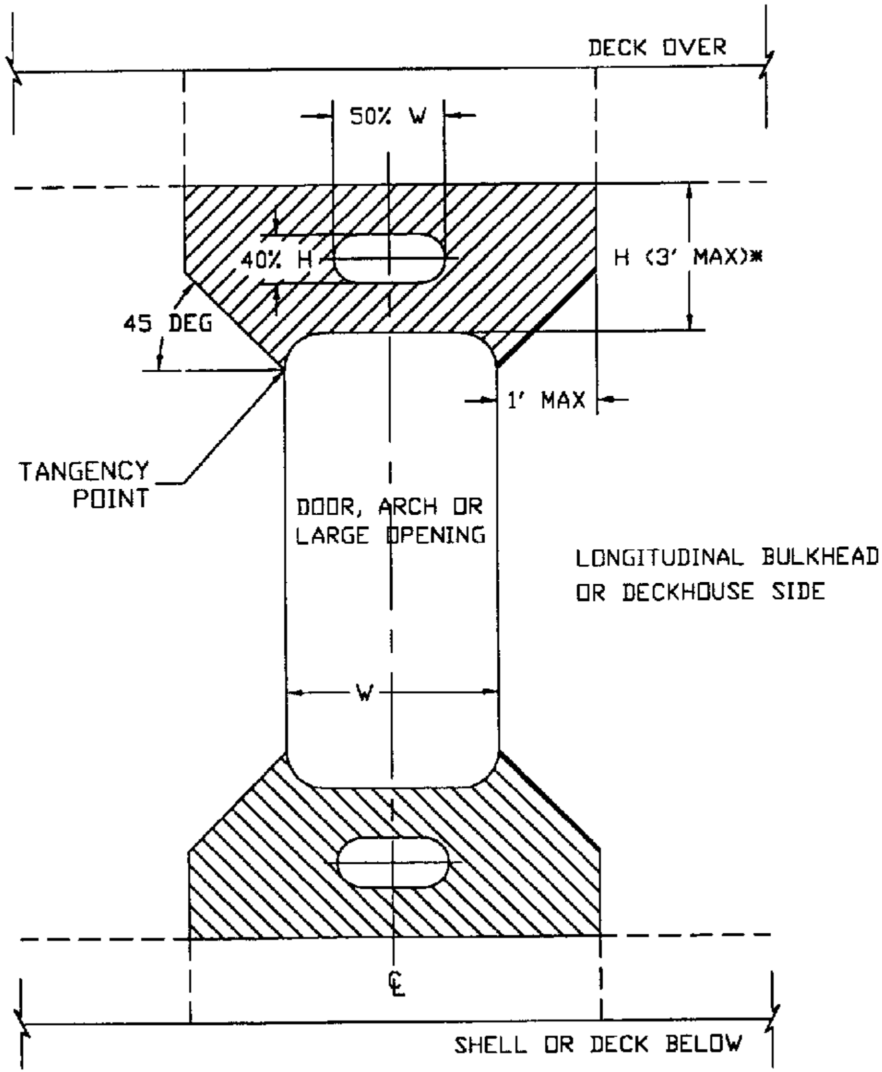
RESTRICTED AREAS FOR HOLES IN MISCELLANEOUS AREAS

VITECH, INC.

NONE

FIG. 13

RESTRICTED AREAS FOR HOLES IN LONGITUDINAL STRUCTURAL BULKHEADS OR DECKHOUSE SIDES

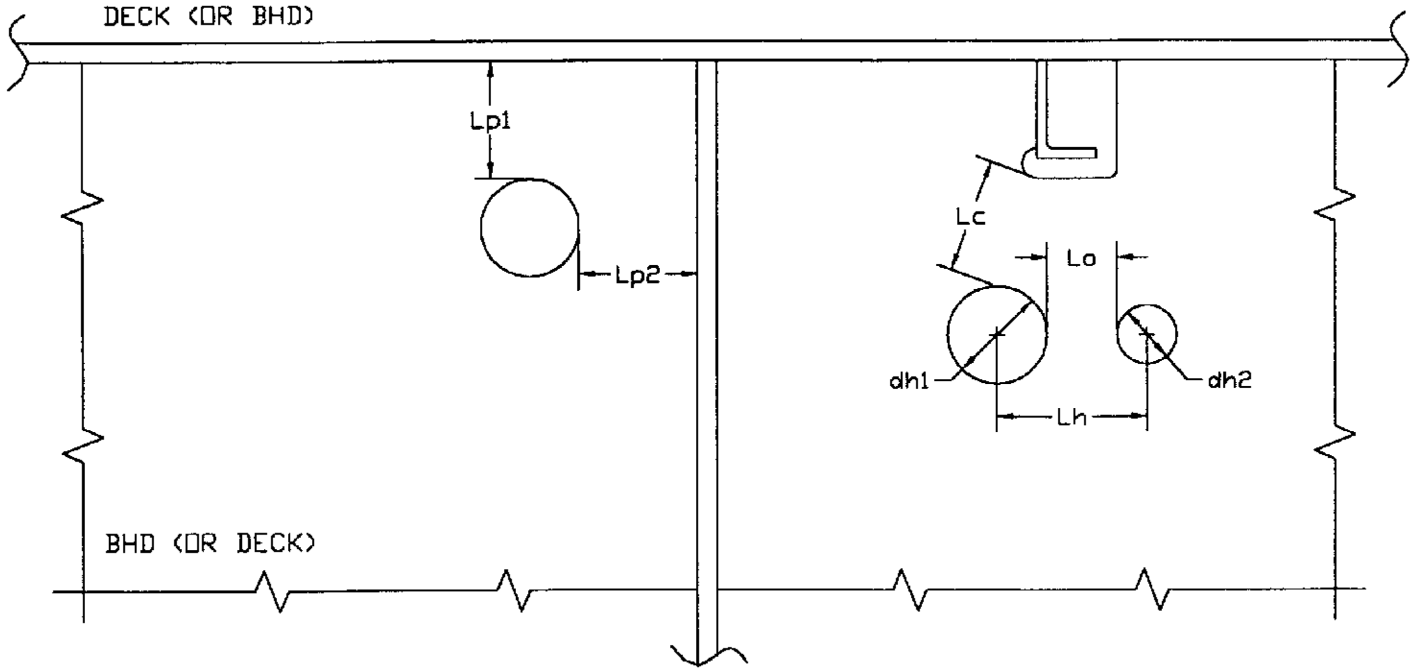


NOTE : IF THE AVAILABLE DISTANCE BETWEEN THE TOP OF THE DOOR/LARGE OPENING AND THE SHELL OR DECK IS LESS THAN 3', THEN H IS EQUAL TO THE AVAILABLE DISTANCE

NO CUTS IN SHADED AREA, EXCEPT ONE CUT AS SHOWN IN BOTH UPPER AND LOWER AREA

NSRP SP-6-95-3	
RESTRICTIONED AREAS FOR HOLES IN LONGITUDINAL STRUCTURAL BULKHEADS	
VIBTECH, INC.	
NONE	FIG. 14

STRUCTURAL DECKS AND BULKHEADS



SIZING CRITERIA

WITHOUT COMPENSATION

Lp1 $\geq$ 6"
Lp2 $\geq$ 6"
Lh $\geq$ dh1 + dh2
Lo $\geq$ 8"
Lc $\geq$ 8"

WITH COMPENSATION

Lp1 $\geq$ 1-1/2" IF Lp2 $\geq$ 3" (AND VICE VERSA)
Lo $\geq$ 3"
Lc $\geq$ 3"

NSRP SP-6-95-3

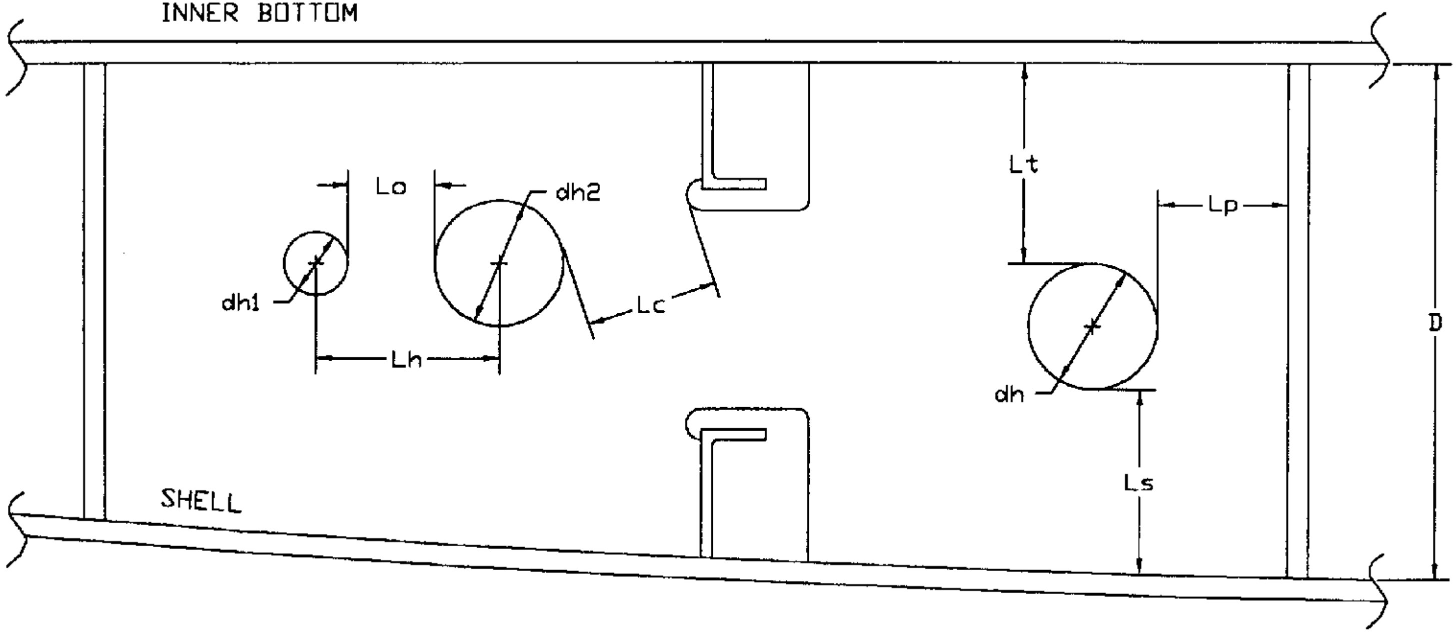
PENETRATIONS IN STRUCTURAL
DECKS AND BULKHEADS

VISTECH, INC.

NONE

FIG. 18

DOUBLE BOTTOM FLOORS AND LONGITUDINAL GIRDERS



SIZING CRITERIA

WITHOUT COMPENSATION

Lp ≥ 6"
Lt ≥ dh
Lt ≥ 6"
Lh ≥ dh1 + dh2
Lo ≥ 8"
Lc ≥ 8"
Ls ≥ dh (TO A MAXIMUM OF D/4)

WITH COMPENSATION

Lp ≥ 1-1/2"
Lt ≥ dh
Lt ≥ 6"
Lo ≥ 3"
Lc ≥ 3"
Ls ≥ dh (TO A MAXIMUM OF D/4)

NSRP SP-6-95-3

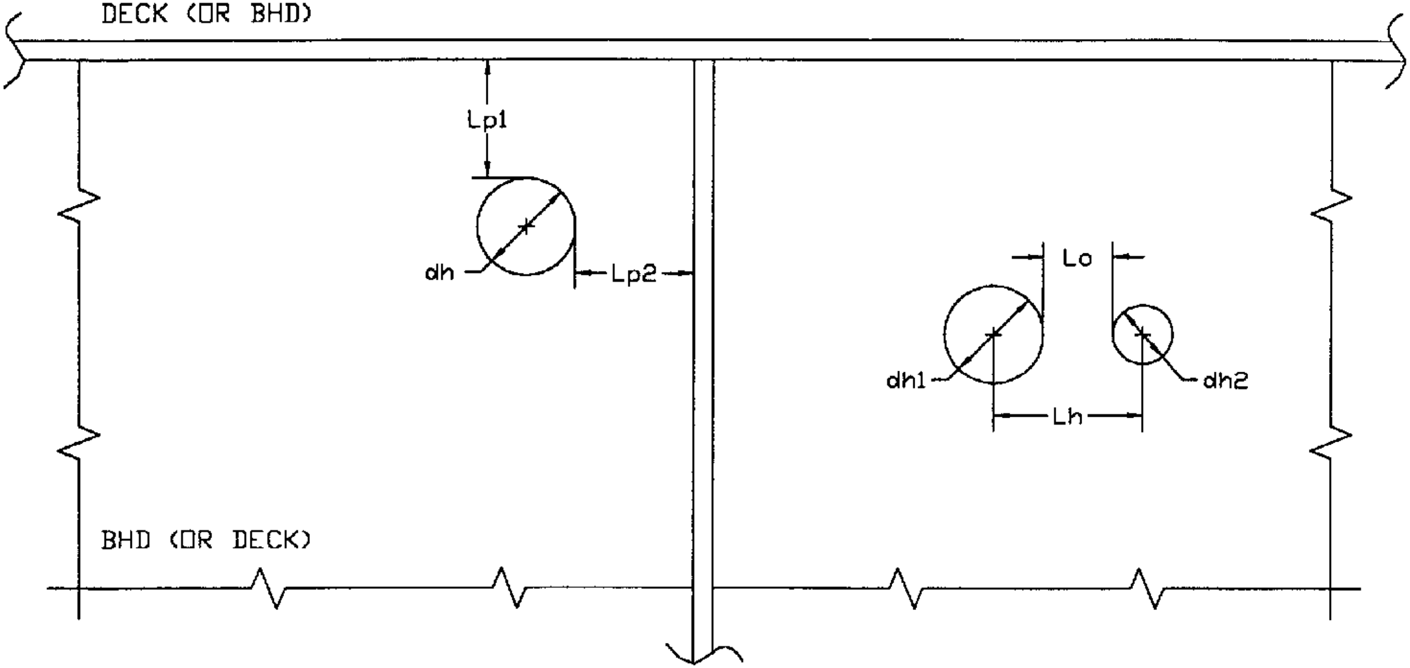
PENETRATIONS IN DOUBLE BOTTOM FLOORS AND LONGITUDINAL GIRDERS

VISTECH, INC.

NONE

FIG. 16

STRENGTH ENVELOPE



NOTES:

1) MULTIPLE OPENINGS NOT ALLOWED TRANSVERSELY
2) AVOID OPENINGS NEAR THE CORNERS OF LARGE OPENINGS SUCH AS HATCHES
3) AVOID OPENINGS NEAR THE ENDS OF OR BREAKS IN SUPERSTRUCTURE OR DECKHOUSES
4) PENETRATIONS DISCOURAGED IN STRENGTH DECK STRINGER PLATES OR SHEER STRAKES WITHIN THE MIDSHIP 3/5 LENGTH, ONLY WHEN VALIDATED BY ENGINEERING

SIZING CRITERIA TO BE MET WITHOUT CONSULTING ENGINEERING

$L_{p1} \geq 6'$

$L_{p2} \geq 6'$

$L_h \geq d_{h1} + d_{h2}$

$L_o \geq 8''$

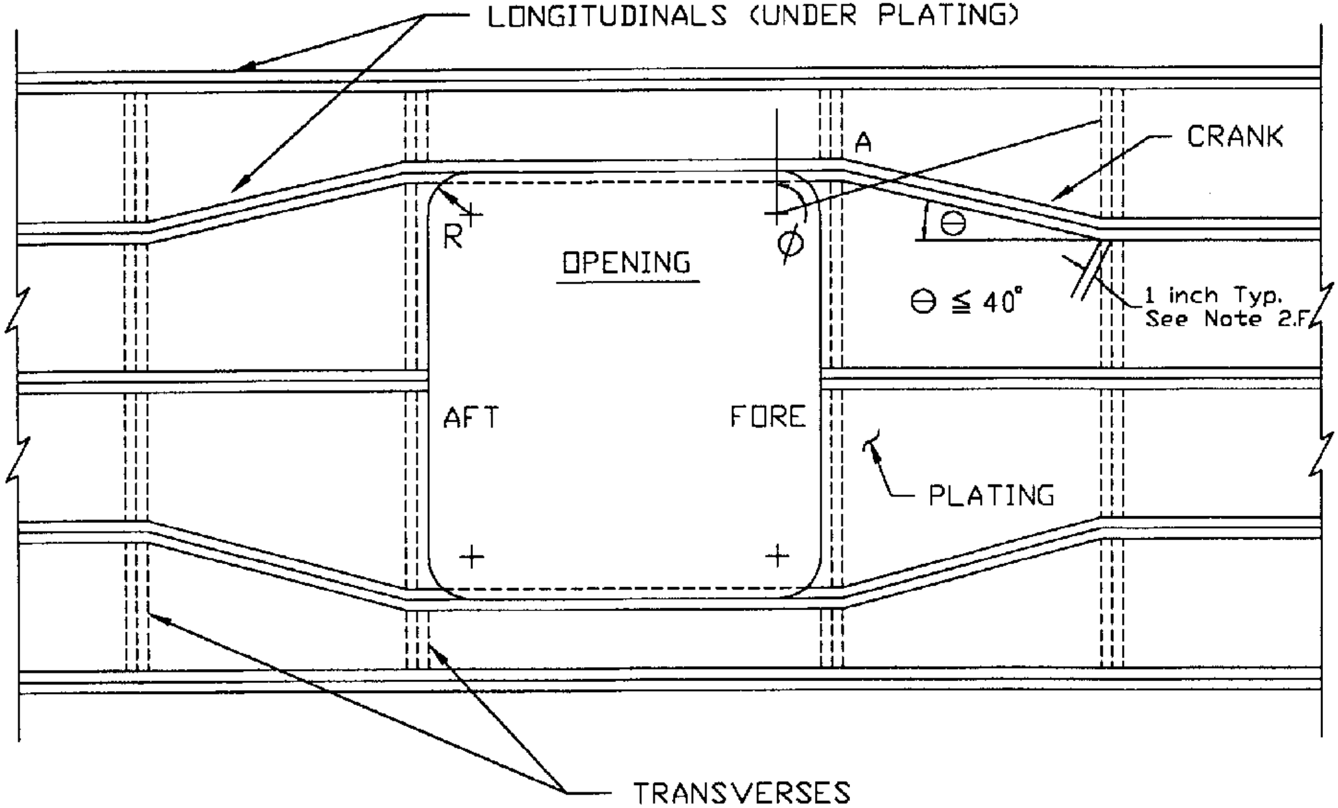
$d_h \leq 9'$

NSRP SP-6-95-3

PENETRATIONS IN STRENGTH ENVELOPE

FIG. 17

OPENING CUTTING LINE OF LONGITUDINALS



THE POSITION OF THE BUTT AT A SHOULD BE AS NEAR AS POSSIBLE TO THE ZERO STRESS CONTOUR, WHERE $50^\circ \leq \phi \leq 70^\circ$

NSRP SP-6-95-3

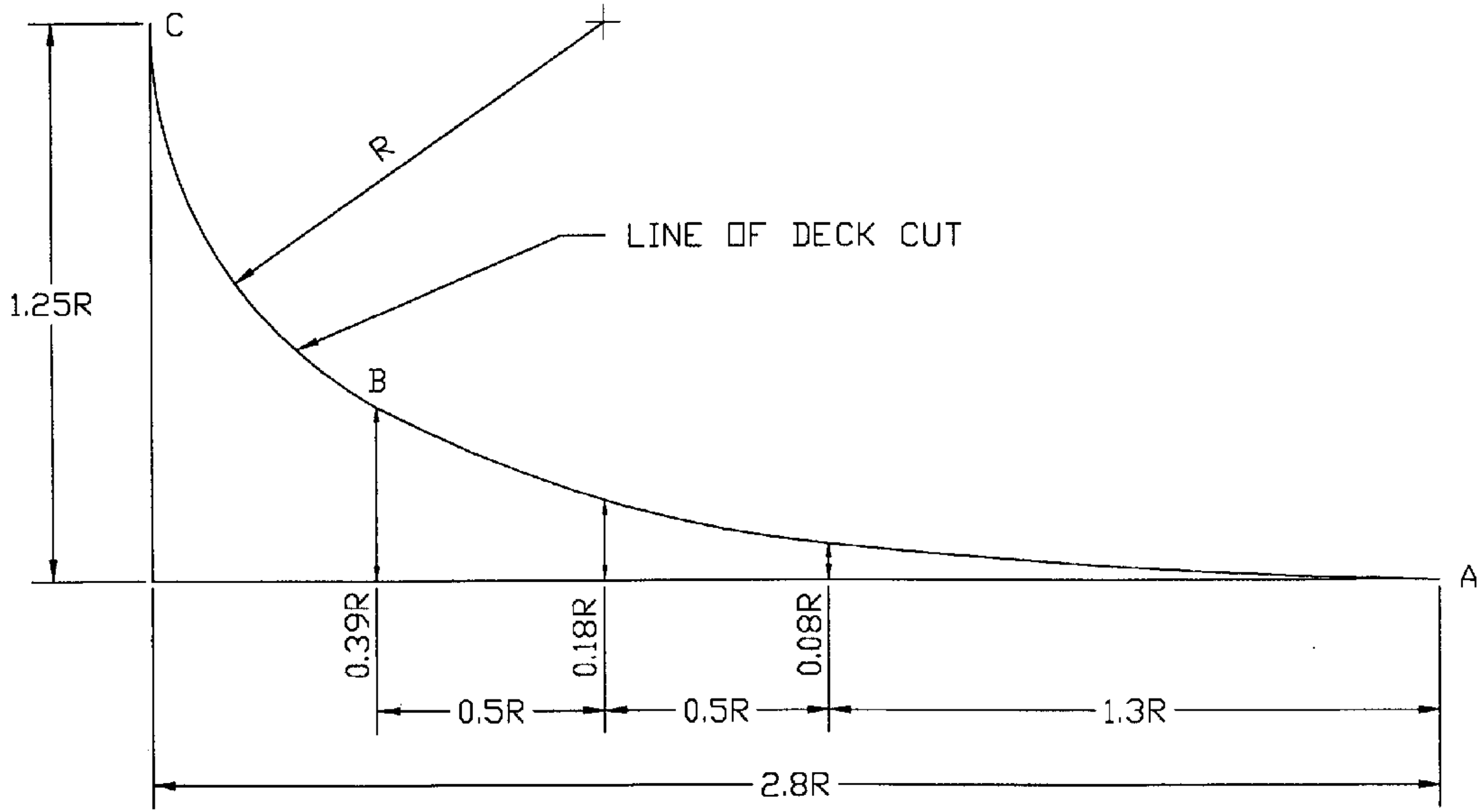
OPENING CUTTING LINE OF LONGITUDINALS

VIBTECH, INC.

NONE

FIG. 18

STREAMLINE CORNER PROFILE FOR LARGE OPENINGS



NOTES :

1. FROM A TO B, THE STREAMLINED CURVE IS AS DEFINED BY THE SKETCH ABOVE. FROM B TO C, THE CURVE IS AN ARC OF A CIRCLE WITH A RADIUS R EQUIVALENT TO THE RADIUS OF CURVATURE AT B.
2. R = 0.04 W, WHERE W = BREADTH OF OPENING.

NSRP SP-6-95-3

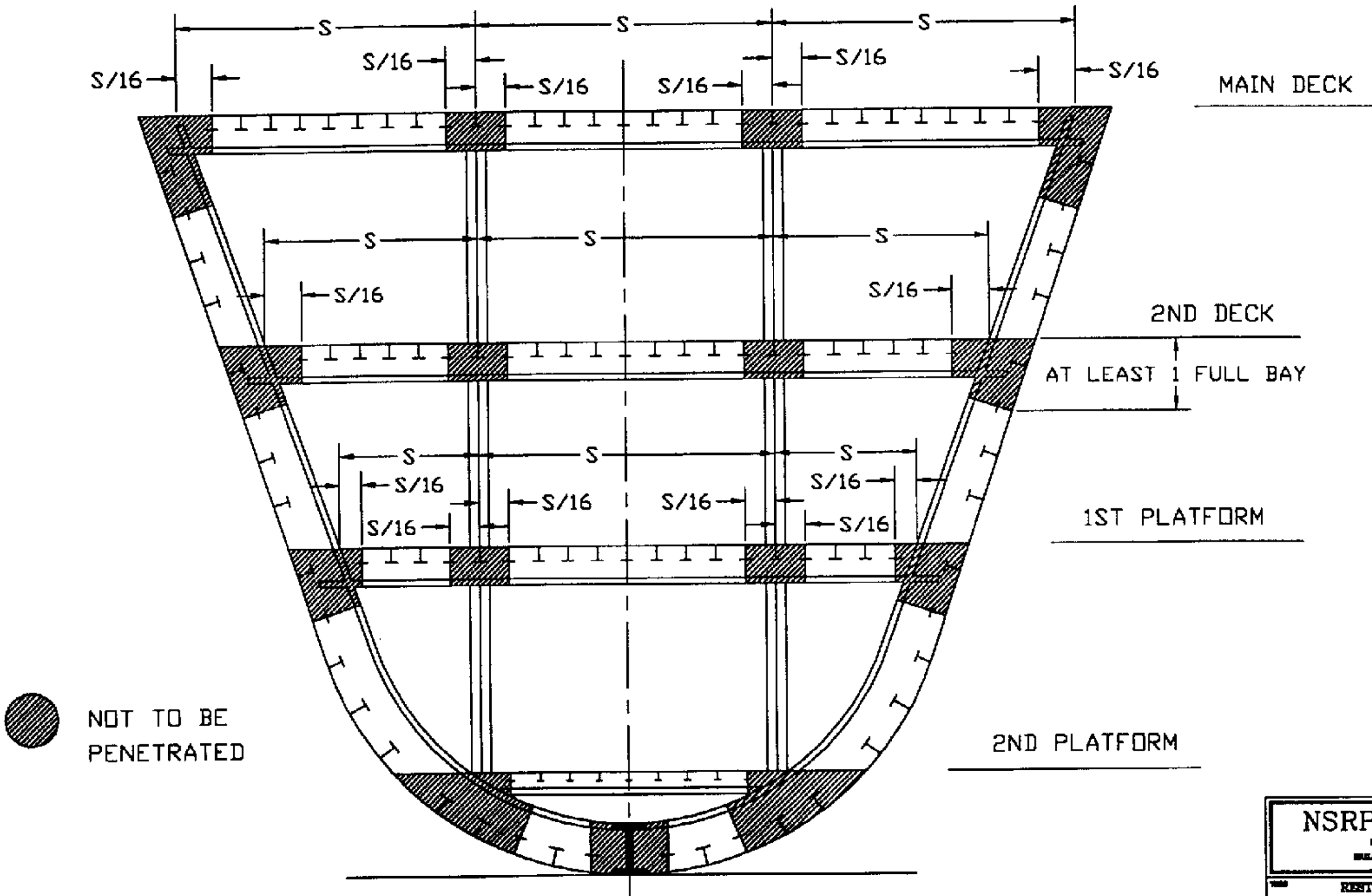
STREAMLINE CORNER PROFILE

VISTECH, INC.

NONE

FIG. 19

RESTRICTED AREAS FOR HOLES IN WEB FRAMES



NOTE : USE S/16 BUT NOT TO BE LESS THAN 1 BAY

NSRP SP-6-95-3	
RESTRICTIONED AREAS FOR HOLES IN WEB FRAMES	
VSTECH, INC.	
NONE	FIG. 20

5.0 Penetration Standard Guidelines -- Design Criteria Tables

SIZE CHART FOR UNCOMPENSATED PENETRATIONS -- FLATOVAL

MIDDLE 3/4 SPAN

BEAM DEPTH (in)	Max. OPENING LENGTH, L (in)	Max. OPENING WIDTH, W (in)
6	4.0	2.0
8	5.3	2.7
10	6.7	3.3
12	8.0	4.0
16	10.7	5.3
20	13.3	6.7
24	16.0	8.0
30	20.0	10.0
36	24.0	12.0
42	28.0	14.0
48	32.0	16.0
54	36.0	18.0
60	40.0	20.0
66	44.0	22.0
72	48.0	24.0

END 1/8 SPAN

BEAM DEPTH (in)	Max. OPENING DIAMETER, dh (in)
6	2.0
8	2.7
10	3.3
12	4.0
16	5.3
20	6.7
24	8.0
30	10.0
36	12.0
42	14.0
48	16.0
54	18.0
60	20.0
66	22.0
72	24.0

* NOTE : ONLY CIRCULAR OPENINGS IN LAST 1/8 SPAN

SIZE CHART FOR UNCOMPENSATED PENETRATIONS -- RECTANGULAR

MIDDLE 2/3 SPAN

BEAM DEPTH (in)	Max. OPENING LENGTH, L (in)	Max. OPENING WIDTH, W (in)	Min. CORNER RADIUS, R (in)
6	4.0	2.0	1.5
8	5.4	2.7	1.5
10	6.7	3.3	1.5
12	8.0	4.0	1.5
16	10.7	5.3	1.5
20	13.4	6.7	1.7
24	16.1	8.0	2.0
30	20.1	10.0	2.5
36	24.1	12.0	3.0
42	28.1	14.0	3.5
48	32.2	16.0	4.0
54	36.2	18.0	4.5
60	40.2	20.0	5.0
66	44.2	22.0	5.5
72	48.2	24.0	6.0

END 1/6 SPAN

BEAM DEPTH (in)	Max. OPENING DIAMETER, dh (in)
6	2.0
8	2.7
10	3.3
12	4.0
16	5.3
20	6.7
24	8.0
30	10.0
36	12.0
42	14.0
48	16.0
54	18.0
60	20.0
66	22.0
72	24.0

* NOTE : ONLY CIRCULAR OPENINGS IN LAST 1/6 SPAN

SIZE CHART FOR UNCOMPENSATED PENETRATIONS -- ELLIPTICAL

MIDDLE 3/4 SPAN

BEAM DEPTH (in)	Max. OPENING LENGTH, L (in)	Max. OPENING WIDTH, W (in)
6	4.8	2.4
8	6.4	3.2
10	8.0	4.0
12	9.6	4.8
16	12.8	6.4
20	16.0	8.0
24	19.2	9.6
30	24.0	12.0
36	28.8	14.4
42	33.6	16.8
48	38.4	19.2
54	43.2	21.6
60	48.0	24.0
66	52.8	26.4
72	57.6	28.8

END 1/8 SPAN

BEAM DEPTH (in)	Max. OPENING DIAMETER, dh (in)
6	2.0
8	2.7
10	3.3
12	4.0
16	5.3
20	6.7
24	8.0
30	10.0
36	12.0
42	14.0
48	16.0
54	18.0
60	20.0
66	22.0
72	24.0

* NOTE : ONLY CIRCULAR OPENINGS IN LAST 1/8 SPAN

FACE BAR COMPENSATION -- NON-CIRCULAR OPENINGS

TABLE 1

		PARENT PLATE THICKNESS (in)									
OPENING	OPENING	0.25		0.375		0.5		0.625		0.75	
DEPTH, W (in)	LENGTH, L (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)
3	3	1.50	0.250	2.00	0.250	2.00	0.375	---	---	---	---
3	6	1.50	0.250	2.00	0.250	2.00	0.375	---	---	---	---
3	9	2.00	0.250	3.00	0.250	2.50	0.375	---	---	---	---
4	4	1.50	0.250	2.00	0.250	2.00	0.375	2.00	0.500	---	---
4	8	2.00	0.250	2.50	0.250	2.50	0.375	2.00	0.500	---	---
4	12	2.50	0.250	4.00	0.250	3.50	0.375	3.00	0.500	---	---
6	6	1.50	0.250	2.00	0.250	2.00	0.375	2.00	0.500	2.00	0.625
6	12	2.50	0.250	4.00	0.250	3.50	0.375	3.00	0.500	3.00	0.625
6	18	4.00	0.250	5.50	0.250	5.00	0.375	4.50	0.500	4.50	0.625
8	8	2.00	0.250	2.50	0.250	2.50	0.375	2.00	0.500	2.00	0.625
8	16	3.50	0.250	5.00	0.250	4.50	0.375	4.00	0.500	4.00	0.625
8	24	5.00	0.250	7.50	0.250	6.50	0.375	6.00	0.500	6.00	0.625
10	10	2.00	0.250	3.00	0.250	3.00	0.375	2.50	0.500	2.50	0.625
10	20	4.00	0.250	6.00	0.250	5.50	0.375	5.00	0.500	5.00	0.625
10	30	4.00	0.375	6.00	0.375	8.00	0.375	7.50	0.500	7.50	0.625
12	12	---	---	4.00	0.250	3.50	0.375	3.00	0.500	3.00	0.625
12	24	---	---	7.50	0.250	6.50	0.375	6.00	0.500	6.00	0.625
12	36	---	---	7.50	0.375	10.00	0.375	9.00	0.500	9.00	0.625
15	15	---	---	---	---	4.00	0.375	4.00	0.500	4.00	0.625
15	30	---	---	---	---	8.00	0.375	7.50	0.500	7.50	0.625
15	45	---	---	---	---	9.00	0.500	11.50	0.500	11.00	0.625
18	18	---	---	---	---	---	---	4.50	0.500	4.50	0.625
18	36	---	---	---	---	---	---	9.00	0.500	9.00	0.625
18	54	---	---	---	---	---	---	11.00	0.625	13.00	0.625

NOTE: FACE BAR WIDTH IS DENOTED AS b AND FACE BAR THICKNESS IS DENOTED AS Tc

FACE BAR COMPENSATION -- NON-CIRCULAR OPENINGS

TABLE 2

		PARENT PLATE THICKNESS (in)									
OPENING	OPENING	0.875		1		1.125		1.25		1.5	
DEPTH, W (in)	LENGTH, L (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)
10	10	2.50	0.750	2.50	0.875	2.50	1.000	2.50	1.125	---	---
10	20	5.00	0.750	5.00	0.875	4.50	1.000	4.50	1.125	---	---
10	30	7.00	0.750	7.00	0.875	7.00	1.000	7.00	1.125	---	---
12	12	3.00	0.750	3.00	0.875	3.00	1.000	3.00	1.125	3.00	1.375
12	24	6.00	0.750	5.50	0.875	5.50	1.000	5.50	1.125	5.50	1.375
12	36	8.50	0.750	8.50	0.875	8.50	1.000	8.00	1.125	8.00	1.375
15	15	3.50	0.750	3.50	0.875	3.50	1.000	3.50	1.125	3.50	1.375
15	30	7.00	0.750	7.00	0.875	7.00	1.000	7.00	1.125	7.00	1.375
15	45	10.50	0.750	10.50	0.875	10.50	1.000	10.00	1.125	10.00	1.375
18	18	4.50	0.750	4.50	0.875	4.50	1.000	4.00	1.125	4.00	1.375
18	36	8.50	0.750	8.50	0.875	8.50	1.000	8.00	1.125	8.00	1.375
18	54	13.00	0.750	12.50	0.875	12.50	1.000	12.00	1.125	12.00	1.375
21	21	5.00	0.750	5.00	0.875	5.00	1.000	5.00	1.125	5.00	1.375
21	42	10.00	0.750	10.00	0.875	9.50	1.000	9.50	1.125	9.50	1.375
21	63	15.00	0.750	14.50	0.875	14.50	1.000	14.00	1.125	14.00	1.375
24	24	6.00	0.750	5.50	0.875	5.50	1.000	5.50	1.125	5.50	1.375
24	48	11.50	0.750	11.00	0.875	11.00	1.000	11.00	1.125	10.50	1.375
24	72	17.00	0.750	16.50	0.875	16.50	1.000	16.00	1.125	16.00	1.375
30	30	---	---	7.00	0.875	7.00	1.000	7.00	1.125	7.00	1.375
30	60	---	---	14.00	0.875	13.50	1.000	13.50	1.125	13.50	1.375
30	90	---	---	18.00	1.000	20.50	1.000	20.00	1.125	20.00	1.375
36	36	---	---	---	---	8.50	1.000	8.00	1.125	8.00	1.375
36	72	---	---	---	---	16.50	1.000	16.00	1.125	16.00	1.375
36	108	---	---	---	---	22.00	1.125	24.00	1.125	24.00	1.375

NOTE: FACE BAR WIDTH IS DENOTED AS b AND FACE BAR THICKNESS IS DENOTED AS Tc

FACE BAR COMPENSATION -- CIRCULAR OPENINGS

TABLE 1

OPENING DIAMETER, D (in)	PARENT PLATE THICKNESS (in)									
	0.25		0.375		0.5		0.625		0.75	
	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)
3	1.50	0.250	2.00	0.250	2.00	0.375	---	---	---	---
4	1.50	0.250	2.00	0.250	2.00	0.375	2.00	0.500	---	---
6	1.50	0.250	2.00	0.250	2.00	0.375	2.00	0.500	2.00	0.625
8	2.00	0.250	2.50	0.250	2.50	0.375	2.00	0.500	2.00	0.625
10	2.00	0.250	3.00	0.250	3.00	0.375	2.50	0.500	2.50	0.625
12	---	---	4.00	0.250	3.50	0.375	3.00	0.500	3.00	0.625
15	---	---	---	---	4.00	0.375	4.00	0.500	4.00	0.625
18	---	---	---	---	---	---	4.50	0.500	4.50	0.625

FACE BAR COMPENSATION -- CIRCULAR OPENINGS

TABLE 2

OPENING DIAMETER, D (in)	PARENT PLATE THICKNESS (in)									
	0.875		1		1.125		1.25		1.5	
	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)	b (in)	Tc (in)
10	2.50	0.750	2.50	0.875	2.50	1.000	2.50	1.125	---	---
12	3.00	0.750	3.00	0.875	3.00	1.000	3.00	1.125	3.00	1.375
15	3.50	0.750	3.50	0.875	3.50	1.000	3.50	1.125	3.50	1.375
18	4.50	0.750	4.50	0.875	4.50	1.000	4.00	1.125	4.00	1.375
21	5.00	0.750	5.00	0.875	5.00	1.000	5.00	1.125	5.00	1.375
24	6.00	0.750	5.50	0.875	5.50	1.000	5.50	1.125	5.50	1.375
30	---	---	7.00	0.875	7.00	1.000	7.00	1.125	7.00	1.375
36	---	---	---	---	8.50	1.000	8.00	1.125	8.00	1.375

NOTE: FACE BAR WIDTH IS DENOTED AS b AND FACE BAR THICKNESS IS DENOTED AS Tc

STANDARD SIZE SPOOLS AND PIPES ARE ENCOURAGED FOR USE IF THEY MEET THE ABOVE CRITERIA

DOUBLER COMPENSATION TABLE

PARENT PLATE THICK, Tp (in) =>	0.25		0.375			0.5			0.625			0.75		
DOUBLER PLATE THICK, Td (in) =>	0.25	0.3125	0.3125	0.375	0.4375	0.4375	0.5	0.5625	0.5625	0.625	0.6875	0.6875	0.75	0.8125
OPENING DEPTH W (in)	DOUBLER DEPTH d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)	d (in)
4	2.0	1.6	2.4	2.0	1.7	--	--	--	--	--	--	--	--	--
5	2.5	2.0	3.0	2.5	2.1	2.9	2.5	2.2	--	--	--	--	--	--
6	3.0	2.4	3.6	3.0	2.6	3.4	3.0	2.7	3.3	3.0	2.7	--	--	--
7	3.5	2.8	4.2	3.5	3.0	4.0	3.5	3.1	3.9	3.5	3.2	3.8	3.5	3.2
8	4.0	3.2	4.8	4.0	3.4	4.6	4.0	3.6	4.4	4.0	3.6	4.4	4.0	3.7
9	4.5	3.6	5.4	4.5	3.9	5.1	4.5	4.0	5.0	4.5	4.1	4.9	4.5	4.2
10	5.0	4.0	6.0	5.0	4.3	5.7	5.0	4.4	5.6	5.0	4.5	5.5	5.0	4.6
12	--	--	7.2	6.0	5.1	6.9	6.0	5.3	6.7	6.0	5.5	6.5	6.0	5.5
14	--	--	--	--	--	8.0	7.0	6.2	7.8	7.0	6.4	7.6	7.0	6.5
15	--	--	--	--	--	--	--	--	8.3	7.5	6.8	8.2	7.5	6.9
16	--	--	--	--	--	--	--	--	8.9	8.0	7.3	8.7	8.0	7.4
18	--	--	--	--	--	--	--	--	--	--	--	9.8	9.0	8.3

PARENT PLATE THICK, Tp (in) =>	0.875			1.0			1.125			1.25			1.5	
DOUBLER PLATE THICK, Td (in) =>	0.8125	0.875	0.9375	0.9375	1.0	1.0625	1.0625	1.125	1.1875	1.1875	1.25	1.375	1.375	1.5
OPENING DEPTH (IN) W (in)	DOUBLER DEPTH d (in)	d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)	d (in)	DOUBLER DEPTH d (in)	d (in)
10	5.4	5.0	4.7	--	--	--	--	--	--	--	--	--	--	--
11	5.9	5.5	5.1	5.9	5.5	5.2	--	--	--	--	--	--	--	--
12	6.5	6.0	5.6	6.4	6.0	5.6	6.4	6.0	5.7	--	--	--	--	--
14	7.5	7.0	6.5	7.5	7.0	6.6	7.4	7.0	6.6	7.4	7.0	6.4	--	--
15	8.1	7.5	7.0	8.0	7.5	7.1	7.9	7.5	7.1	7.9	7.5	6.8	8.2	7.5
16	8.6	8.0	7.5	8.5	8.0	7.5	8.5	8.0	7.6	8.4	8.0	7.3	8.7	8.0
18	9.7	9.0	8.4	9.6	9.0	8.5	9.5	9.0	8.5	9.5	9.0	8.2	9.8	9.0
20	10.8	10.0	9.3	10.7	10.0	9.4	10.6	10.0	9.5	10.5	10.0	9.1	10.9	10.0
22	11.8	11.0	10.3	11.7	11.0	10.4	11.6	11.0	10.4	11.6	11.0	10.0	12.0	11.0
25	13.5	12.5	11.7	13.3	12.5	11.8	13.2	12.5	11.8	13.2	12.5	11.4	13.6	12.5
28	--	--	--	14.9	14.0	13.2	14.8	14.0	13.3	14.7	14.0	12.7	15.3	14.0
30	--	--	--	--	--	--	15.9	15.0	14.2	15.8	15.0	13.6	16.4	15.0
33	--	--	--	--	--	--	--	--	--	17.4	16.5	15.0	18.0	16.5
36	--	--	--	--	--	--	--	--	--	--	--	--	19.6	18.0

INSERT PLATE COMPENSATION TABLE

OPENING DEPTH, W (in)	BEAM DEPTH (in)														
	6	8	10	12	16	20	24	30	36	42	48	54	60	66	72
3	2.00	1.60	1.43	---	---	---	---	---	---	---	---	---	---	---	---
4	3.00	2.00	1.67	1.50	---	---	---	---	---	---	---	---	---	---	---
5	---	2.67	2.00	1.71	1.45	---	---	---	---	---	---	---	---	---	---
6	---	---	2.50	2.00	1.60	1.43	---	---	---	---	---	---	---	---	---
8	---	---	---	3.00	2.00	1.67	1.50	---	---	---	---	---	---	---	---
10	---	---	---	---	2.67	2.00	1.71	1.50	---	---	---	---	---	---	---
12	---	---	---	---	---	2.50	2.00	1.67	1.50	---	---	---	---	---	---
15	---	---	---	---	---	---	2.67	2.00	1.71	1.56	---	---	---	---	---
18	---	---	---	---	---	---	---	2.50	2.00	1.75	1.60	---	---	---	---
21	---	---	---	---	---	---	---	---	2.40	2.00	1.78	1.64	1.54	---	---
24	---	---	---	---	---	---	---	---	3.00	2.33	2.00	1.80	1.67	1.57	---
27	---	---	---	---	---	---	---	---	---	2.80	2.29	2.00	1.82	1.69	1.60
30	---	---	---	---	---	---	---	---	---	---	2.67	2.25	2.00	1.83	1.71
33	---	---	---	---	---	---	---	---	---	---	---	2.57	2.22	2.00	1.85
36	---	---	---	---	---	---	---	---	---	---	---	3.00	2.50	2.20	2.00
40	---	---	---	---	---	---	---	---	---	---	---	---	3.00	2.54	2.25
45	---	---	---	---	---	---	---	---	---	---	---	---	---	---	2.67

NOTE 1: VALUES LISTED ARE MULTIPLIERS. SIMPLY FIND THE APPROPRIATE VALUE AND MULTIPLY IT BY THE PARENT PLATE THICKNESS TO OBTAIN THE INSERT PLATE THICKNESS. (i.e., T2 = Tp x MULTIPLIER)

6.0 Conclusions & Recommendations

After the initial literature search and extensive survey through shipyards and regulatory bodies, it was determined that there are no existing industry-wide standards for penetration in secondary ship structure. However, in case of major openings and penetrations in primary structures, there is consistency in the guidelines and practices followed in shipbuilding industry. While, these guidelines and practices have been used for decades, not much effort has been undertaken to technically upgrade these guidelines and practices into an industry standard, using state-of-art design methodologies and computational tools.

Furthermore, the rules of classification societies & regulatory bodies are general and really only address the issues of major openings. It is difficult for designers and drafters to implement those rules on secondary and discretionary penetrations. The task for each shipyard to develop penetration standards has been handed to engineering who have had to conduct in-house case by case analyses to establish a penetration design and control plan. Since the rules are so general, these in-house efforts have lead to varying guidelines depending on how the rules were implemented.

Implementing varying designs and/or not having any penetration standards, increases the engineering costs, decreases the benefits which can be achieved from commonality in design and production, and subsequently increases the production cost and time.

The Standard Penetration Handbook will resolve such problems to a great extent, especially in the general area of ship structure design and construction. It will enhance the design development process, help to establish common and similar designs leading to faster cycle time and thereby achieve time and cost reduction.

This document will also provide guidance and methods to further extend the standard penetration design guidelines to special and high-strength steel, and to special purpose ship/marine structures. Work in these areas definitely need some attention and collaborative effort, and the authors highly recommend that the NSRP Ship Production Committees take the initiative in completing the effort.

Appendix A

NSRP -- SP6

PROJECT 6-95-3

INDUSTRY STANDARDS FOR HULL STRUCTURAL PENETRATION DESIGN CRITERIA AND DETAILS

TECHNICAL REPORT

Table of Contents

1.0 Overview --- --- --- --- --- --- --- --- --- A-3

2.0 Information Search --- --- --- --- --- --- --- --- A-3

3.0 Collation of Information --- --- --- --- --- --- --- A-4

4.0 Develop Design Guidelines for Standard Penetration Details --- --- A-4

4.a Establish criteria and requirements
4.b Establish parameters for design guidelines
4.c Develop algorithms for design guidelines
4.d Establish Standard Penetration Details & Structural Configurations
4.e Circulate Standard Penetration Design Criteria / Guidelines and Details

5.0 Develop CAD Drawings and Databases --- --- --- --- --- A-24

5.a Create CAD Drawings of Standard Penetration Details & Structural Configurations
5.b Develop Database for Family of Standard Penetration Details
5.c Incorporate Changes to Include Shipyard Feed-back

6.0 Develop Standard Hull Structural Penetration Handbook and Submit to ASTM --- --- A-26

NSRP SP-6 PROJECT 6-95-3

INDUSTRY STANDARDS FOR HULL STRUCTURAL PENETRATION DESIGN CRITERIA AND DETAILS

TECHNICAL REPORT

1.0 Overview

The objective of this project is to develop a standard design guide handbook for structural penetrations in secondary ship structure. The handbook contains design criteria and details for use by designers and drafters to enhance ship construction drawing development. Standard penetration design criteria and details are developed through parametric evaluation of ship structural openings, using first principles engineering and detail finite element analysis. These design criteria and details will enable designers and drafters to have guidance in the design of penetrations without having to resort to time consuming engineering review of each penetration.

The technical approach taken to accomplish this project and develop the handbook can be broadly categorized in five successive tasks, i.e., Information Search; Collation of Information; Design Guidelines Development; CAD Drawings and Database Development; & Standard Hull Structural Penetration Handbook Development.

2.0 Information Search

Collection and compilation of all the relevant material was undertaken in this task. A Literature search was conducted to search and compile relevant documents, papers, and information pertaining to penetration and compensation in ship structures.

Six major shipyards were contacted for their existing standards/guidelines for penetration and compensation in secondary ship structure. Many shipyards have performed extensive analyses on structural penetrations and have in-house penetration design guidelines. These guidelines may differ slightly from yard to yard. In addition, a questionnaire to various shipyards was sent asking questions about planning, procedures, criteria and specifications for structural penetration.

Three major regulatory bodies were contacted for their existing rules/guidelines for penetration and compensation in secondary ship structure. These rules upon application may have resulted in differing reinforcements and construction details, thus incorporation of these rules in the design criteria and details of standard penetration guidelines will eliminate such varying designs.

3.0 Collation of Information

Under this task the information and data collected by the efforts of previous task are reviewed. The information/data collected and reviewed include

- The existing standards/guidelines for penetrations in various shipyards
- Responses to questionnaire on penetration standard & practice from various shipyards
- Rules and guidelines of USCG and ABS
- SSC Reports (e.g. SSC 266 & SSC 272)
- ASTM Standards (e.g. F994-86 & F1455-92)
- NAVSEA DDS 100-2 & DDS 100-8
- Vibtech's in-house databases, reports and documents

By reviewing the above, valuable information and data were extracted and a set of guidelines was framed to select candidate penetration and reinforcement details and design criteria. The selected details and criteria are such that they represent a wide array of penetration sizes, shapes, locations, reinforcement methods and parent structural members.

Thereafter, efforts are made to distill out representative penetration and reinforcement details from the selected candidate details. These representative design criteria and details have wider applicability than selected candidate details, and therefore are more suitable for standard details.

4.0 Develop Design Guidelines for Standard Penetration Details

Efforts undertaken in this task, the core of the entire project, were to develop the complete set of penetration and reinforcement design criteria and guidelines and establish family of standard penetration details and reinforcement methods. The standards established in this task are further developed into CAD drawings and databases that are included in the final design handbook.

4.a Establish criteria and requirements

Based on the results of a review of shipyard standards, questionnaire, and an in-house literature search, criteria and requirements for penetration standards were established. The parent structures chosen for most of the investigations are the under deck girders. The responses to the questionnaire seemed to indicate that under deck girders and side shell frames caused the greatest structural problems. Under deck girders are chosen for representation since their loading scenarios are more harsh and therefore will provide the limiting case for the study.

Three girder sizes corresponding to three ship sizes (DWT ranges 20,000-40,000; 40,000-80,000; 80,000-120,000) were initially studied. Preliminary results indicated that stress is more closely tied to relative geometry than absolute size so eventually only one girder size was evaluated. The girder scantlings and loadings were determined using the container loading and section modulus criteria from the ABS rules. After a short study it was determined that modeling half the beam using a fixed-fixed condition would be appropriate. The representative penetration configurations analyzed were longitudinal cut-outs, circles, flat-ovals, rectangulars with radiused corner and ellipticals. The compensation methods chosen were doublers, inserts, flat bar rings and standard spool/pipes.

The limiting criteria chosen for strength adequacy is a nominal stress value not exceeding 60% of Yield Strength, which for mild-steel is 60% of 34 KSI, approximately 20 KSI (same allowed by ABS), and a local peak stress value not exceeding 90% of Yield Strength, which for mild-steel is 30.6 KSI. The allowable stress range for fatigue details was obtained from "ABS Steel Vessel Rules Part 5 Section 2 Appendix 5/2AA -- Guide for Fatigue Assessment of Tankers", where fatigue allowable stress ranges are defined for each classification of details in Table 5/2AA.1. The penetration and cut-out details can be very conservatively assumed to fall in the Category C – Parent material with automatic flame-cut edges. Taking a very conservative approach, the fatigue allowable for the Category C detail results in an allowable stress range of 68.23 KSI. The fatigue assessment is discussed in section 4.c.

Shipyard standard allowable penetration sizes were used as a starting point for the initial round of analysis. Finite element models were run for all selected penetration shapes, both with and without longitudinal cut-out interaction. Results obtained were used to establish overall allowable dimensions, allowable locations along the beam and distance away from the flange, and allowable spacing in way of other penetrations. These values were obtained both for compensated and uncompensated penetrations.

4.b Establish parameters for design guidelines

The final design handbook contains standard representative details and design guidelines, thus a parametric approach to penetration and reinforcement variables was taken in the analysis, so that standard guidelines are not restricted by size and location but have wide applicability.

Cutouts for Longitudinal Members geometries were chosen by consulting the shipyard standards. The allowable depth of the cutout was determined to be 33% of the girder depth based on ABS requirements. The compensations used for cutouts were lap lugs and full watertight collars. Three cutout sizes, 33%, 40% and 60% of the girder depth, respectively, were modeled based on required section modulus rules from ABS.

The system penetration geometries and relative sizes were chosen based on shipyard responses and their standards. These chosen configurations were the starting point for further

analyses. Various finite element models were analyzed by varying the parameters and geometry of system penetrations, pushing the variables of existing allowables but still maintaining a reasonable safety factor. The system penetration parameters were also analyzed for allowables at various structural zones. The interaction of multiple penetrations and effects of proximity of penetrations were also studied. Various types of compensations and reinforcements for penetrations were also analyzed.

Parameters for cut-outs and system penetrations interaction were obtained using the results from previous analyses, along with some more parametric variation analyses for cut-outs and system penetrations. Finite element models were analyzed by varying the parameters and geometry of cut-outs and system penetrations, pushing the variables of existing allowables but still maintaining reasonable safety factors. The interaction of cutouts with closely positioned penetrations were analyzed. Various types of compensations and reinforcements for cut-outs and penetrations were evaluated for close proximity scenarios.

4.c Develop algorithms for design guidelines

Guidelines and simple empirical algorithms were developed for designing penetrations in secondary structures and small secondary penetrations in primary structures. The guidelines/algorithms were also derived for cut-outs with appropriate references to the ABS rules. These design guidelines were arrived at from the results of earlier tasks, existing standards and more refined and focused finite element analyses based on the selected parameters.

Detailed finite element models (FEM), which accurately represent the geometry in high stress areas were run. The Von-Mises stresses in these models are kept below the stress limitations. The finite element models are modeled in 2-D with very fine mesh ,with element sizes of approximately 0.5 inch square at the high stress areas around the penetrations and cut-outs. The peak stresses were taken at the nodes at the edge of the penetrations, not an average for the elements, so that actual edge stress is determined. Figures 1 & 2 show the FEMs of Cut-outs and penetrations for a few of the analyzed cases, and Figure 3 shows the stress distribution in the case of close proximity of penetration to a cut-out.

NSRP SP6-95-3

UNDER-DECK GIRDER, HALF BEAM LENGTH W/ CUT-OUTS FOR LONGITUDINALS

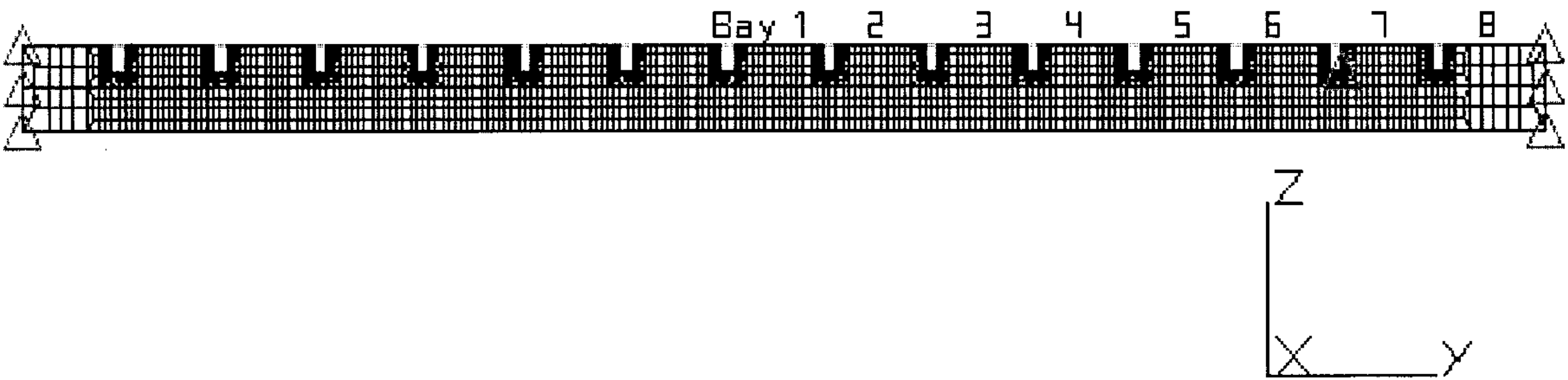


Figure 1

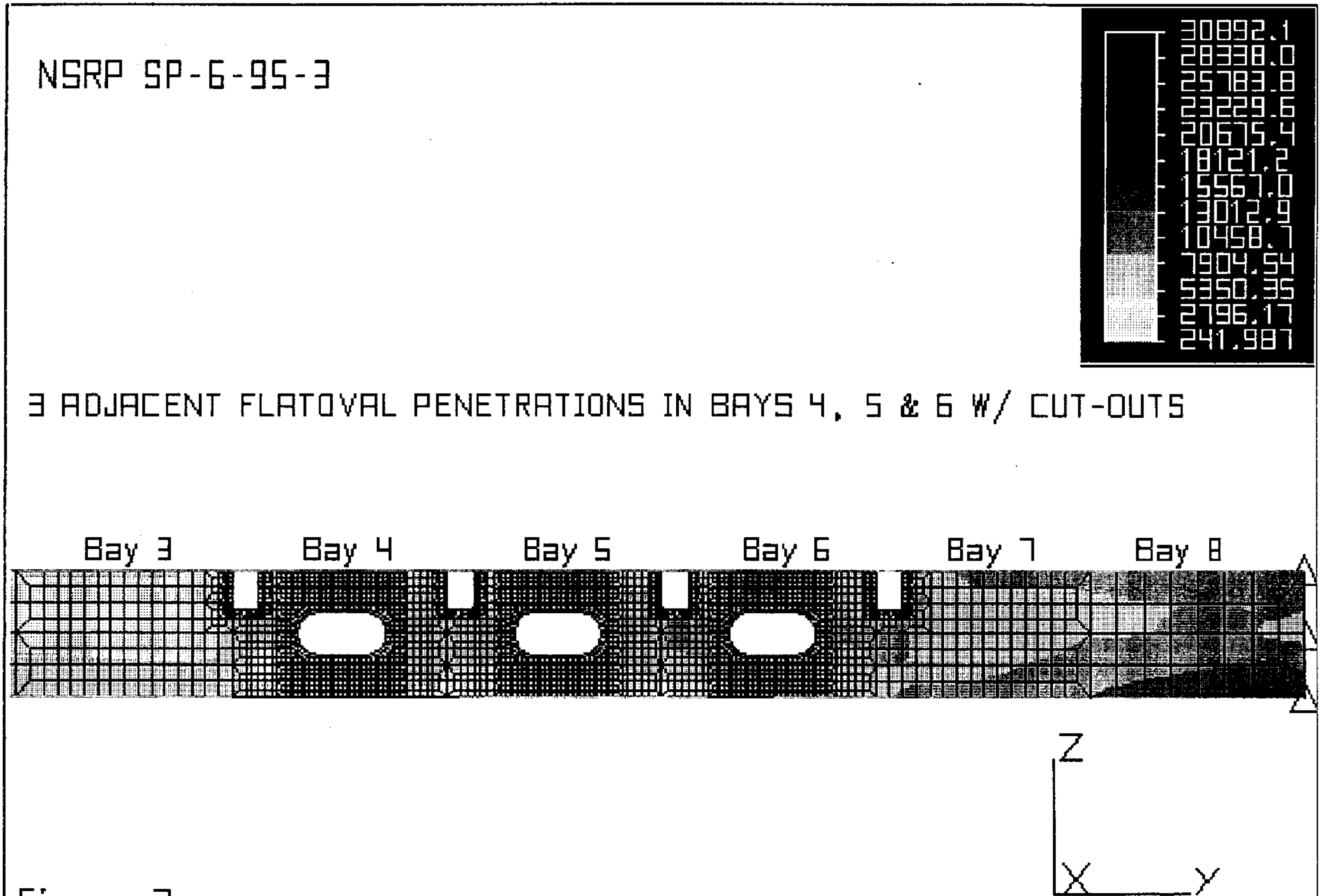
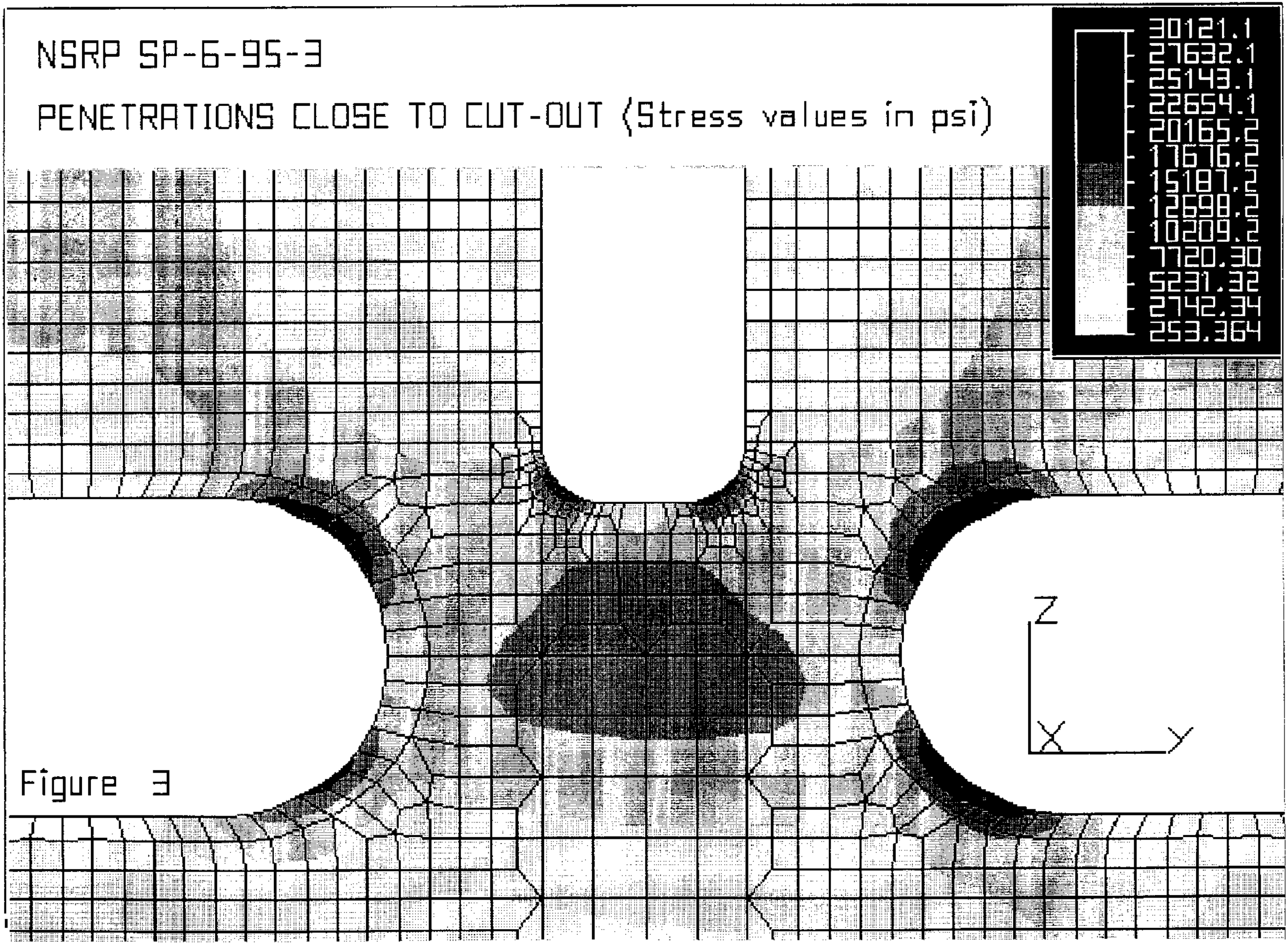


Figure 2

Von Mises Stress



Von Mises Stress

Finite element analysis results of various representative structural configurations, with varying penetration and cut-out types, sizes and numbers were tabulated in this section. The FEA models were made of the under-deck girder, with container loading. The under-deck girder is divided into 15 equal bays, by under-deck beams. Figure 1 shown earlier describes this base-line FEM illustration.

Table 1 shows the stress output for 7 different FEMs. Each FEM was developed as a flat-oval penetration of length 66% of girder depth (D) and depth of 40% D, with one cut-out on each side of penetration. The depth of cut-outs are 33% D. Each of the 7 FEMs has the penetration in a different bay, with the first model having the penetration in Bay 1 (center most bay) and gradually moving to Bay 2 and so on, in the successive models. A Bay is defined as the length of the under-deck girder between two adjacent under-deck beams. However, in the seventh model with penetration being in Bay 7, the depth of the penetration was decreased to 33% D. The stress concentration factor (SCF) in Table 1 are the ratios of the peak stresses to the average stress at the top of the web in that particular bay. The peak stress values which are more than the design allowable of 30.6 KSI, are highlighted by being enclosed in thick line boxes.

Table 2 shows the stress output for 21 different FEMs of flatoval and 3 different FEMs of rectangular penetrations. Of 21 flatoval models, seven models are for each of 3 penetration sizes. The length of the penetration sizes are the same, being 66% D, however, the depths are 33% D, 40% D, and 50% D, respectively. The seven models for each of the penetration sizes are as described in the paragraph above. The SCF is the ratio of the peak stress to the analytically obtained nominal stress at that bay. Of the 3 rectangular models, 2 have the same penetration length and depth i.e. 66% D and 33% D, respectively, but located at Bay 4 and Bay 5. The third model has the penetration in Bay 6 with penetration size reduced to 50% D by 25% D. All of the rectangular penetrations have a corner radii of ¼ of the depth of the opening. The last row of data show the stresses at the cut-outs, which are 33% D in depth, these cut-out stresses are highlighted because they can be substantial, due to tight corner radii of rectangular penetration with close proximity to cut-outs.

Table 3 shows the stress output for 2 FEMs of round and 1 of elliptical penetration, respectively. Of round penetration models, one has an opening diameter of 40% D placed in Bay 7, and the other has of 50% D placed in Bay 6. For the elliptical penetration model, the length of the opening is 80% D and depth 40% D, placed in Bay 6. Under both penetration types, the stresses at the cut-outs are also mentioned.

Table 4 shows the stress output for 3 different FEMs, for 3 different cut-out sizes. The width of the cut-out sizes are the same, being 20% D, whereas, the depths are 33% D, 40% D, and 60% D, respectively. The FEMs have 14 cutouts modeled one at each under-deck beam location. The SCF are the ratios of the peak stresses to the nominal stress at that cut-out location.

NSRP SP6 PROJECT
FLAT OVAL HOLE RESULTS
1/7/98

STRESSES IN KSI

47 ft BEAM FOR 33" DEEP GIRDER (t = .5")
FLAT OVAL DEPTH 40% OF GIRDER DEPTH, D (33% @ BAY 7)
ALLOWABLE 90% OF YIELD = 30.6 KSI (YIELD = 34 KSI)

BEAM (ft) =47 | w (lbs/in) = 256.1

	CENTER OF HALF BEAM BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6	BAY 7	END OF HALF BEAM BAY 8
AVERAGE STRESS TOP	4.4	6.0	8.0	10.7	13.7	15.1	18.0	
LEFT CUT-OUT MAX	4.7	10.2	15.1	19.1	22.3	25.9	34.3	
SCF	1.07	1.70	1.89	1.80	1.63	1.71	1.91	
RIGHT CUT-OUT MAX	5.3	11.8	18.0	24.1	27.2	30.0	39.2	
SCF	1.22	1.97	2.26	2.27	1.98	1.99	2.18	
OVAL TOP MAX	4.2	6.2	11.4	15.5	19.6	27.8	33.7	
SCF	0.96	1.03	1.43	1.45	1.43	1.85	1.87	
AVERAGE STRESS BOTTOM	10.2	10.2	9.3	7.9	7.6	11.0	14.8	
OVAL BOTTOM MAX	10.4	12.6	14.4	15.1	16.1	23.5	29.3	
SCF	1.02	1.24	1.55	1.92	2.12	2.14	1.98	

Table 1

NSRP SP6 PROJECT
FLAT OVAL & RECTANGULAR HOLE RESULTS
1/7/98
STRESSES IN KSI

47 ft BEAM FOR 33" DEEP GIRDER (t = .5")

FLAT-OVAL & RECTANGULAR PENETRATIONS CLOSE TO CUT-OUTS

ALLOWABLE 90% OF YIELD = 30.6 KSI (YIELD = 34 KSI)

BEAM (ft) = 47 | w (lbs/in) = 256.1

	CENTER OF HALF BEAM BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6	BAY 7	END OF HALF BEAM BAY 8
DISTANCE FROM END, X (ft)	11.75	8.47	5.19	1.91	-1.37	-4.65	-7.93	
MOMENT @ X (Kips.in)	849	650	55	-937	-2325	-4111	-6293	
SECTION MODULUS (in^3)	372.9	372.9	372.9	372.9	372.9	372.9	372.9	
NOMINAL STRESS @ X	2.3	1.7	0.1	2.5	6.2	11.0	16.9	
FEA Results :								
FLAT-OVAL --								
PEAK STRESS @ PEN, 33%D	9.0	11.5	13.3	14.5	18.8	26.7	33.5	
SCF	3.95	6.60	90.04	5.78	3.02	2.42	1.99	
PEAK STRESS @ PEN, 40%D	10.4	12.6	14.4	15.5	19.6	27.8	34.9	
SCF	4.57	7.23	97.49	6.15	3.14	2.53	2.07	
PEAK STRESS @ PEN, 50%D	12.6	15.7	40.5	35.5	31.8	FAIL	FAIL	
SCF	5.53	9.00	274.18	14.14	5.09			
RECTANGULAR --								
PEAK STRESS @ PEN, 33%D	---	---	---	22.02	30.70	---	---	
PEAK STRESS @ PEN, 25%D L 50% D	---	---	---	---	---	30.78	---	
PEAK STRESS @ CUT, 33%D	---	---	17.0	24.1	30.3	29.6	---	

Table 2

NSRP SP6 PROJECT
ROUND & ELLIPTICAL HOLE RESULTS
1/7/98
STRESSES IN KSI

47 ft BEAM FOR 33" DEEP GIRDER (t = .5")

ROUND & ELLIPTICAL PENETRATIONS CLOSE TO CUT-OUTS

ALLOWABLE 90% OF YIELD = 30.6 KSI (YIELD = 34 KSI)

	CENTER OF HALF BEAM		BEAM (ft) =47		w (lbs/in) = 256.1			END OF HALF BEAM
	BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6	BAY 7	BAY 8
DISTANCE FROM END, X (ft)	11.75	8.47	5.19	1.91	-1.37	-4.65	-7.93	
MOMENT @ X (Kips.in)	849	650	55	-937	-2325	-4111	-6293	
SECTION MODULUS (in^3)	372.9	372.9	372.9	372.9	372.9	372.9	372.9	
NOMINAL STRESS @ X	2.3	1.7	0.1	2.5	6.2	11.0	16.9	
FEA Results :								
ROUND --								
PEAK STRESS @ PEN, 40%D	---	---	---	---	---	---	26.4	
PEAK STRESS @ PEN, 50%D	---	---	---	---	---	25.6	---	
PEAK STRESS @ CUT, 33%D	---	---	---	---	26.8	$\boxed{31.7}$	$\boxed{39.8}$	
ELLIPTICAL --								
PEAK STRESS @ PEN, 40%D L 80% D	---	---	---	---	---	26.3	---	
PEAK STRESS @ CUT, 33%D	---	---	---	---	28.8	30.6	---	

Table 3

NSRP SP6 PROJECT
CUT-OUT RESULTS
1/7/98
STRESSES IN KSI

47 ft BEAM FOR 33" DEEP GIRDER (t = .5")
VARIABLE CUT-OUT DEPTHS (Width, CW = 0.2D)
ALLOWABLE 90% OF YIELD = 30.6 KSI (YIELD = 34 KSI)

BEAM (ft) = 47 | w (lbs/in) = 256.1

	CENTER OF HALF BEAM BAY 1	BAY 2	BAY 3	BAY 4	BAY 5	BAY 6	BAY 7	END OF HALF BEAM BAY 8
DISTANCE FROM END, X (ft)	10.11	6.83	3.55	0.27	-3.01	-6.29	-9.57	
MOMENT @ X (Kips.in)	799	402	-391	-1582	-3169	-5152	-7533	
SECTION MODULUS (in^3)	372.9	372.9	372.9	372.9	372.9	372.9	372.9	
NOMINAL STRESS @ X	2.1	1.1	1.0	4.2	8.5	13.8	20.2	
FEA Results :								
PEAK STRESS, CUTOUT 33%D	5.0	10.9	16.6	22.1	27.4	33.0	38.5	
SCF	2.34	10.14	15.80	5.21	3.22	2.39	1.90	
PEAK STRESS, CUTOUT 40%D	4.4	10.9	17.5	24.1	30.7	33.0	41.6	
SCF	2.07	10.13	16.66	5.67	3.61	2.39	2.06	
PEAK STRESS, CUTOUT 60%D	7.9	14.3	21.9	31.2	40.7	44.2	54.4	
SCF	3.67	13.25	20.92	7.35	4.79	3.20	2.69	

Table 4

Table 5 shows the stress output for 8 different FEMs. These models were run to investigate the interaction of penetrations with adjacent penetrations and/or cut-outs. The first two rows of results are for models with three (3) flatoval penetrations in adjacent bays with adjacent cut-outs also modeled. The penetration dimensions considered were length equal to 66% D and depth of 33% D, see figure 2. Two models were analyzed with penetrations being in bays 1, 2 & 3, in one case, and in bays 4, 5 & 6 in the second case. Two more models were analyzed with similar penetration dimensions and locations, but with penetrations closely located with only 66% D distance between them. The results are shown in the second row.

In Table 5 the next two rows of results are from models which analyze the interaction of cut-out and penetration when located very close to each other, with some form of compensation/reinforcement on either one of them. The row 3 shows results of 3 closely located uncompensated flatoval penetrations in bays 4, 5 & 6, also positioned within 15% D to adjacent cut-out compensated with lap-lug. Row 4 shows results of a similar model, but with face-bar (ring) compensated penetration with increased depth of 40% D and uncompensated cut-out.

In addition, additional investigation was done to evaluate the impact of concentrated loads from track vehicles on penetration sizes and locations. Row 5 of Table 5 shows results of a model of three (3) closely located flatoval penetrations of sizes and locations mentioned before, with two (2) times the uniformly distributed load obtained from container loading, applied at alternate bays. Furthermore, the same model was again run with three (3) times the uniformly distributed load, applied at every third bay, the results of which are shown in row 6 of Table 5.

NSRP SP6 PROJECT
MULTIPLE FLATOVALS RESULTS
1/7/98
STRESSES IN KSI

47 ft BEAM FOR 33" DEEP GIRDER (t = .5")
ALLOWABLE 90% OF YIELD = 30.6 KSI (YIELD = 34 KSI)
FLAT OVAL DEPTH 33.3% & LENGTH 66.6% OF GIRDER DEPTH

	CENTER OF HALF BEAM BAY 1	BAY 2	BEAM (ft) = 47 BAY 3	BAY 4	w (lbs/in) = 256.1 BAY 5	BAY 6	BAY 7	END OF HALF BEAM BAY 8
PEAK STRESS @ PENETRATN 3 ADJACNT FLATOVALS	9.1	11.2	13.5	14.5	18.7	26.9	---	
PEAK STRESS @ PENETRATN 3 CLOSE ADJACNT FLATOVALS	8.3	10.9	13.4	14.8	19.7	25.5	---	
PEAK STRESS @ PENETRATN 3 CLOSE ADJACNT FLATOVALS W/ CUT-OUT LAP-LUG	---	---	---	14.8	20.8	25.5	---	
PEAK STRESS, PENETRATN OF 40% D, RING COMPENSATED W/ CUT-OUT	---	---	---	15.4	22.4	26.4	---	
PEAK STRESS @ PENETRATN 3 CLOSE ADJACNT FLATOVALS ALTERNATE 2xUNIF. DIS. LOAD	---	---	---	15.5	18.5	26.4	---	
PEAK STRESS @ PENETRATN 3 CLOSE ADJACNT FLATOVALS INTERMITTNT 3xUNIF. DIS. LOAD	---	---	---	17.7	16.5	27.2	---	

Table 5

Table 6 shows the results from FEMs of flatoval penetrations of depth of half of girder depth, i.e. W = 0.5 D, with various methods of compensation. The amount of compensation/ reinforcement required was based on the area of the missing material due to the opening. The existing standards' guidelines for reinforcements were adopted as the starting point. The first 3 rows show the results of openings of length equal to 80% of girder depth, with each row showing results of 2 models with one type of compensation, namely Doubler, Flatbar, or Insert Plate. Each one of these models have modeled one opening in the middle of a bay and an outboard cut-out. The second 3 rows show the results of the same types of models except for the length of the opening being 100% of the girder depth. Similarly, the third 3 rows show results that are of openings with length of 120% of girder depth. Of the last 3 rows, each row shows results of one finite element model, each modeled with two openings next to each other with lengths equal to 150% of girder depth, and with no cut-outs modeled. The first one of these 3 models has 100% of Doubler compensation around each opening as required, with a distance of 67% of girder depth between openings. The second model has 75% of the required Doubler compensation, with a distance of 33% of girder depth between openings. Whereas, the third model has the required Flatbar compensation around the openings, with a distance of 33% of girder depth between openings.

Table 7 shows the results from FEMs of rectangular penetrations of corner radii, R, of 25% of penetration depth, W, with various methods of compensation, and varying distances between opening and cut-out. The table shows results of 4 finite element models, each one of which has two openings, one in Bay 5 and the other in Bay 6, and three cut-outs modeled. The opening in Bay 5 has a length of 100% and depth of 50% of girder depth, respectively. Whereas, the opening in Bay 6 has a length of 67% and depth of 33% of girder depth, respectively. The first model has compensation in the form of an Insert plate around the openings, and has openings placed only 3" from their nearest respective outboard cut-outs. The second model also has the same clearance between openings and cut-outs, but has a Flatbar ring around the openings. The third model also has Flatbar ring compensation, but the openings are placed 6" from the nearest respective cut-outs. The fourth model was developed the same as the third one, except the cut-outs were reinforced with Lap Lugs.

Based on the results of these detailed analyses, a set of guidelines for standard penetration details, geometry and configurations have been established from a strength point of view. Thereupon, these guidelines were evaluated using fatigue criteria. ABS design rules for fatigue were consulted for the evaluation.

NSRP SP6 PROJECT
FLATOVAL W/ COMPENSATIONS RESULTS
1/7/98
STRESSES IN KSI

47 ft BEAM FOR 33" DEEP GIRDER (t = .5")
VARIABLE FLATOVAL LENGTHS W/ COMPENSATIONS (Depth, W = 0.5D)
ALLOWABLE 90% OF YIELD = 30.6 KSI (YIELD = 34 KSI)

BEAM (ft) = 47	w (lbs/in) = 256.1

	COMPENSATION TYPE	BAY 4	MIDBAY	BAY 5	CUTOUT	BAY 6	CUTOUT	BAY 7
L = 0.8 D PEAK STRESS @ PENETRATN & CUT-OUT 1 HOLE MODEL	Doubler	---	---	15.6	30.4	20.3	28.5	
	Flatbar	---	---	17.2	30.5	22.3	28.9	
	Insert	---	---	13.7	27.9	17.7	26.3	
L = 1.0 D PEAK STRESS @ PENETRATN & CUT-OUT 1 HOLE MODEL	Doubler	---	---	16.8	30.2	22.0	$\boxed{31.0}$	
	Flatbar	---	---	18.7	30.3	24.3	$\boxed{32.3}$	
	Insert	---	---	15.0	26.2	19.6	23.2	
L = 1.2 D PEAK STRESS @ PENETRATN & CUT-OUT 1 HOLE MODEL	Doubler	---	---	21.0	$\boxed{35.9}$	$\boxed{45.4}$	$\boxed{55.3}$	
	Flatbar	---	---	22.0	$\boxed{39.4}$	$\boxed{52.5}$	$\boxed{54.8}$	
	Insert	---	---	18.4	24.8	$\boxed{41.8}$	$\boxed{33.4}$	
L = 1.5 D PEAK STRESS @ PENETRATN & CUT-OUT 2 HOLE MODEL	100% Doubler 67%D Betwn Openings	19.6	8.0	26.0	---	---	---	
	75% Doubler 33%D Betwn Openings	20.2	14.0	26.4	---	---	---	
	Flatbar 33%D Betwn Openings	23.5	22.5	$\boxed{30.7}$	---	---	---	

Table 6

NSRP SP6 PROJECT
RECTANGULAR W/ COMPENSATIONS RESULTS
1/7/98
STRESSES IN KSI

47 ft BEAM FOR 33" DEEP GIRDER (t = .5")
VARIABLE RECTANGULAR SIZES W/ COMPENSATIONS (Corner Radii, R = 0.25 W)
ALLOWABLE 90% OF YIELD = 30.6 KSI (YIELD = 34 KSI)

BEAM (ft) = 47	w (lbs/in) = 256.1

	COMPENSATION TYPE	BAY 4	CUTOUT	BAY 5	CUTOUT	BAY 6	CUTOUT	BAY 7
BAY 5, L x W = 1.0D x 0.5D **BAY 6, L x W = 0.67D x 0.33D** PEAK STRESS @ PENETRATN & CUT-OUT 2 HOLE MODEL	Insert Openings 3" from Cutouts	---	15.9	$\boxed{30.7}$	29.5	30.0	27.2	
BAY 5, L x W = 1.0D x 0.5D **BAY 6, L x W = 0.67D x 0.33D** PEAK STRESS @ PENETRATN & CUT-OUT 2 HOLE MODEL	Flatbar Openings 3" from Cutouts	---	27.3	$\boxed{31.3}$	$\boxed{47.4}$	28.1	$\boxed{34.4}$	
BAY 5, L x W = 1.0D x 0.5D **BAY 6, L x W = 0.67D x 0.33D** PEAK STRESS @ PENETRATN & CUT-OUT 2 HOLE MODEL	Flatbar Openings 6" from Cutouts	---	30.2	$\boxed{31.1}$	$\boxed{38.0}$	26.2	$\boxed{31.4}$	
BAY 5, L x W = 1.0D x 0.5D **BAY 6, L x W = 0.67D x 0.33D** PEAK STRESS @ PENETRATN & CUT-OUT 2 HOLE MODEL	Flatbar Cutouts w/ Lap Lug Openings 6" from Cutouts	---	29.9	$\boxed{30.7}$	30.2	26.5	28.0	

Table 7

Under fatigue adequacy, the allowable stress was defined in terms of a range of stress which occurs as a result of cyclic loading. By the ABS method the cyclic loading was taken as the maximum cyclic load which was likely to occur during the life of the ship. The resulting stress range which would occur due to the largest cyclic load was compared to a fatigue allowable stress range.

The allowable stress range for fatigue details are categorized by detail geometry. In "ABS Steel Vessel Rules Part 5 Section 2 Appendix 5/2AA -- Guide for Fatigue Assessment of Tankers", fatigue allowable stress ranges are defined for each classification of details in Table 5/2AA.1. The penetration and cut-out details can be very conservatively assumed to fall in the Category C – Parent material with automatic flame-cut edges. The allowable stress range is dependent on the long term distribution parameter for the detail based on the ship's length and the detail's location. Taking the most conservative assumption of ship length = 624 ft, and detail location parameter, $\alpha = 0.86$, the long-term stress distribution parameter, γ comes to 0.97. Linearly interpolating the data in Table 5/2AA.1 for the Category C detail results in an allowable stress range of 47.98 Kgf/mm^2 or 68.23 KSI.

For mild-steel, the allowable stress range for fatigue is greater than the allowable stress limit for strength, i.e. 68.23 KSI > 30.6 KSI x 2, thus strength is always the controlling criteria and fatigue need not be checked, except for special cases. However, for high-strength steel, the strength allowable stress limit is higher than fatigue allowable stress range, i.e. 90% of 51 KSI x 2 = 45.9 KSI x 2 > 68.23 KSI. With this limitation in mind, the penetration guidelines were developed for mild-steel only, as development of high-strength steel guidelines for a variety of ship sizes and penetration locations is beyond the scope of this project. When developing one's own criteria for high-strength steel, the user should note that the overall limits of special steels can often be governed by fatigue and not strength.

In addition, penetration and cut-out configurations which require compensations for strength adequacy were also evaluated for fatigue adequacy. The results show that fatigue generally is not the limiting factor as long as the penetration and cut-out configurations meet the strength criteria, and the level of workmanship for cutting and welding meet the ABS requirements. Thus, the guidelines and algorithms developed for designing penetrations from a strength adequacy view-point were re-established after the fatigue assessment.

The guidelines/algorithms were developed with designers as users in mind, and therefore more empirical formulae, graphical representations and tabulated information were included. These first cut guidelines were used as building blocks for Standard Penetration Details and Structural Configurations.

During the tasks of establishing criteria and requirements and establishing parameters for design guidelines, a first iteration to establish the safety factors in criteria was performed. Under follow on tasks those safety factors were re-evaluated and the effects of safety factor variation on design limitations were assessed. The guidelines established were based on implicit safety factors of 1.67 on Von-mises stress for overall strength criteria, safety factor of 1.1 on localized stress and deformation, and 1.15 on an already conservative stress range for fatigue criteria. Low safety factors for localized deformation and fatigue was considered acceptable because firstly, after the initial loadings are imposed on the structure the strain hardening of the edge material at the

openings and cut-outs will likely provide the required fatigue toughness, given appropriate workmanship in construction. Also in cases of one directional loading – such as gravity loads down on a deck, after initial yielding, stresses will redistribute so that yielding will not occur again. Secondly, these guidelines are for secondary structures and discretionary secondary penetrations and therefore do not pose any concern for primary hull structural failure. Thirdly, it allows the guidelines to be pushed to a higher limit to give maximum benefits to designers and reduce fabrication and installation cost associated with higher number of penetrations, without compromising structural integrity.

From our study we found that safety factors inherent in the proposed guidelines were well within the safe design and operation conditions, and any additional safety margin will only be required for design for special cases.

4.d Establish Standard Penetration Details & Structural Configurations

From the design guidelines established earlier a family of Standard Penetration Details were established. These standard details were the distilled versions of the design guidelines and represent penetration details in more general format which can be applied to various ship structures irrespective of their size and location, still incorporating the design criteria and requirements with the appropriate safety factors. The Standard Details include

- Rectangular Openings
- Flatoval Openings
- Circular Openings
- Elliptical Openings
- Multiple Small Openings
- Openings in Proximity to Cut-Outs
- Cut-Outs
- Insert Plate Compensation
- Doubler Compensation
- Flatbar Ring Compensation

The Standards describe the basic relationship between the parameters of the penetration and the relationship of penetration parameters with the parent structural parameters. The penetration compensation details show the method and proportions of the required compensations, both graphically and by empirical equations. Some preliminary CAD drawings were also framed up for these standards. The Standard Penetration Details were further used in developing the Representative Structural Configurations.

Next, the Standard Penetration Details were applied to various Ship Structure locations. By doing so, Representative Structural Standards were established, which highlight how the penetration details are to be used at various structural locations and/or configurations. These Representative Structural Configurations show the restricted areas for penetrations in both primary structures (Strength Envelope, Bulkhead, Deck, Longitudinal Girders, etc.) and secondary structures (Under-deck girders, Web Frames, Transverse Floors, etc.). These configurations also show the guidelines for penetrations sizes and locations with respect to the

parent structure dimensions and configurations. A few preliminary CAD drawings were framed up to graphically represent these Structural Configurations.

4.e Circulate Standard Penetration Design Criteria / Guidelines and Details

The first-cut design guidelines, algorithms and details with necessary notes were circulated to major shipyards and classification societies/regulatory bodies for their feedback. This gave them a chance to offer their input, comments and changes early in the standard design development phase. This exchange also allowed them to compare and evaluate their existing guidelines/rules in light of new developments accomplished under this project.

5.0 Develop CAD Drawings and Databases

Under this section, CAD drawings and Databases were developed from the standard penetration designs and details and representative structural configurations developed earlier. Efforts were undertaken to develop guidelines for structural penetrations and compensations in easy to use graphical format. Guidelines were specifically arranged for uncompensated and compensated penetrations, with respective allowables and limitations. The guidelines also provided empirical algorithms for penetration compensations. In addition, guidelines for cut-outs for beams/stiffeners were also included. Databases were developed in the form of easy to use tables and charts for standard penetration sizes and locations, and for standard compensation requirements.

5.a Create CAD Drawings of Standard Penetration Details & Structural Configurations

From the family of Standard Penetration Details established earlier, CAD drawings were created to illustrate these standards. These drawings reflect the standard details of different types of opening geometry, namely

- Rectangular Openings
- Flatoval Openings
- Circular Openings
- Elliptical Openings
- Multiple Small Openings

The drawings graphically illustrate and describe the design algorithms and limiting criteria for the basic relationships between the parameters of the penetration and the relationship of penetration parameters with the parent structural parameters. In addition, design algorithms and methods for penetration reinforcements were also illustrated graphically. The drawings also elaborate design algorithms for cut-outs for longitudinal stiffeners, and relationships, limiting criteria and compensations for cut-outs in proximity of openings.

These drawings will be an integral part of the final design guideline and standards. The focus of these CAD drawings is to aid the designer with a pictorial representation of standards and eliminate substantial cost and time associated with calculations.

From the Family of Penetration Details applied to various Representative Structural Configurations earlier, CAD drawings were created to illustrate these configurations. These drawings show the representative structural details with penetrations at various zones of ship structure, and allowables and limitations on introducing penetrations at various structural locations.

The drawings graphically illustrate and describe the design algorithms and limiting criteria for the basic relationships between penetration parameters and the parent structural configurations. The various structural configurations include openings in secondary structures such as under-deck girders, double bottom floors, web frames, non-structural decks and bulkheads, and small secondary and discretionary openings in primary structures including

structural decks and bulkheads, shell plating, longitudinal girders, and strength envelope. These drawings were included in the final design guidelines and standards.

5.b Develop Database for Family of Standard Penetration Details

From the Family of Standard Penetration Details and Algorithms established earlier, databases in the form of tables were developed to summarize these standards. The tables include the sizing chart for uncompensated penetrations at different locations of the ship structure. For guidance purposes the penetration locations were chosen in the under-deck girder, as this location is the most limiting. The sizing charts are developed for different opening geometry, namely

- Rectangular Openings
- Flatoval Openings
- Circular Openings
- Elliptical Openings

In addition, tables were also developed for various compensation types, namely

- Doubler Plate
- Insert Plate
- Flatbar Ring
- Standard Spool/Pipe

These compensation tables can be used to readily read off the required compensation for a given opening size.

These tables will also be an integral part of the final design guideline and standards. The focus of these tables is to aid the designer with readily available standard opening sizes and compensations.

5.c Incorporate Changes to Include Shipyard Feed-back

The feed-back from shipyards and regulatory bodies in response to circulation of preliminary guidelines and CAD drawings were incorporated into the final guidelines and CAD drawings. In order to include some of the suggestions and comments, a few of the tasks were revisited and some of the criteria were re-evaluated.

6.0 Develop Standard Hull Structural Penetration Handbook and Submit to ASTM

Under this final task, the final version of "Industry Standards For Hull Structural Penetration Design Criteria And Details" was compiled. This final document includes

- General Notes
- Notes on Location, Shape, Size and Orientation
- CAD Drawings of Penetration Details
- CAD Drawings of Structural Configurations
- Tables of Standard Penetration Sizing
- Tables of Compensation Requirements

It is proposed that this final document be submitted to ASTM, for them to log the same in their archive of standards and publish an appropriate document to reference this penetration standard which will be a published NSRP document. This penetration standard is not in ASTM format, thus does not need their review and approval, but is in a format proposed by the NSRP panel to be most useful to shipyard designers and drafters.

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